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ADVANCING THE SCIENCE AND ACCEPTANCE OF AUTONOMY FOR FUTURE DEFENSE SYSTEMS

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HOUSE OF REPRESENTATIVES,
COMMITTEE ON ARMED SERVICES,
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES,
Washington, DC, Thursday, November 19, 2015.

The subcommittee met, pursuant to call, at 10:35 a.m., in room 2212, Rayburn House Office Building, Hon. Joe Wilson (chairman of the subcommittee) presiding.

OPENING STATEMENT OF HON. JOE WILSON, A REPRESENTATIVE FROM SOUTH CAROLINA, CHAIRMAN, SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

Mr. WILSON. Ladies and gentlemen, I call this hearing of Emerging Threats and Capabilities Subcommittee of the House Armed Services Committee to order.

I am pleased to welcome everyone here today for today's hearing on advancing the science and acceptance of autonomy for future defense systems. The military necessity for autonomous systems is obvious. Many of us recognize that our military is not large enough, and it is not likely to grow sufficiently over the next few years to handle all the threats we face.

On top of this, shrinking budgets will shrink our military, stretch our military men and women and platforms even further to be able to accomplish their ever-changing and challenging missions. The promise of autonomous systems is becoming more evident every day. From self-driving cars to smart buildings to increasing presence of robotics, the full potential of autonomous systems is nearly endless. What is less understood are the technical and policy challenges that must be identified and solved to make those visions a reality.

Most of us are more likely to understand what is possible with examples provided from television and movies. So I am looking forward to having real experts shed light on what the actual state-of-the-art technology is, and what the path to acceptance looks like for the military services. And with this backdrop, we look forward to hearing from today's panel of witnesses who will educate members on many of the issues related to autonomy research and the development of increasingly autonomous systems.

And we do have a challenge. Votes have just been called, and we will be introducing everyone, and then we will recess and then come back.

And so our witnesses today, Dr. Greg L. Zacharias, Chief Scientist of the U.S. Air Force; Mr. Frank Kelley, Deputy Assistant Secretary of the Navy for Unmanned Systems; Dr. Jonathan Born-

stein, Chief, Autonomous Systems Division, Vehicle Technology Directorate, Army Research Laboratory.

And before we recess, I would like to turn to my friend, the ranking member, James Langevin from Rhode Island, for any comments he'd like to make.

[The prepared statement of Mr. Wilson can be found in the Appendix on page 21.]

STATEMENT OF HON. JAMES R. LANGEVIN, A REPRESENTATIVE FROM RHODE ISLAND, RANKING MEMBER, SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

Mr. LANGEVIN. Well, thank you, Mr. Chairman. And I want to thank you for convening this hearing. I will welcome our witnesses. It is certainly always a pleasure diving into these issues with you. And I appreciate you and your convening this hearing this morning. So again, thank you to our witnesses for appearing before the subcommittee to provide your insights regarding advancing the science of autonomy as well as the challenges with its acceptance.

Increasingly, autonomous systems and capabilities have provided a significant advantage to our warfighters by augmenting the skills while also decreasing the risk to their lives. Some of those systems, such as the human supervised Aegis Combat System, point defense systems such as Phalanx, and ISR [intelligence, surveillance, and reconnaissance] systems, have been such game changers that they have fundamentally altered our strategies and doctrine.

For just one example, as members of the ETC [Emerging Threats and Capabilities] Subcommittee, we are extraordinarily familiar with how remotely piloted aircraft and identifying, tracking, and killing capabilities they carry have not only changed tactic, techniques, and procedures, but also shaped our counterterrorism strategy.

Although we have begun to realize the potential of unmanned systems for military applications, we have yet to grasp the full potential of autonomous systems. Incorporation of unmanned platforms has been driven by demands in current areas of operations, and those same demands will drive us towards usage of increasingly sophisticated autonomy in all domains: air, ground, sea, space, and cyberspace.

Bearing that in mind, it is troubling that the 2012 Defense Science Board [DSB] report entitled "The Report of Autonomy in DOD [Department of Defense] Systems" concluded that there are several hurdles precluding broad acceptance of autonomous systems in the Department, thereby hindering advances in science and technology.

I do recognize that there have been changes and progress on the subject and science of autonomy in the Department since the DSB report was issued. In the fall of 2014, Under Secretary Kendall announced the commissioning of a new study focused on the science, engineering, and policy problems that must be solved to permit greater operational use of autonomy across all warfighting domains. Most recently, the Secretary of the Navy established a new Deputy Assistant Secretary of the Navy for autonomous systems, and a new office to coordinate all aspects of unmanned systems.

And Deputy Secretary Work has indicated autonomous systems will play a significant role in the Third Offset Strategy.

Today, I hope to have a robust dialogue on how we can advance the science, utility, and acceptance of autonomous systems. I hope that we can discuss the following.

First of all, definition. How should we define autonomy? How should we distinguish between the degrees of complexity of autonomous systems? And how should we distinguish future autonomous capabilities?

Next, command and control. Who is ultimately responsible in the chain of command as systems become more independent from operators? Should certain lethal capabilities remain with a human in the loop or become autonomous, akin to point defense systems? When and how should we revisit these determinations?

Next, integration. How will we integrate autonomous systems and capabilities with manned and other unmanned systems across all domains?

Next, science and technology. How do we better transition advancements in capabilities? How will the Department create a cohesive testing and training strategy that provides confidence at the strategic, tactical, and operational levels for maximum employment of the capability? And what hurdles must be overcome to formulate those strategies?

Given that such autonomy research is being undertaken in the private sector, and in our labs and academic institutions, how, and to what degree, do we leverage that work?

And, finally, security and risk. How do we ensure software and hardware systems are secure and verified? How will we understand and measure the risks associated with employment of autonomous systems?

So with that, Mr. Chairman, I look forward to our conversation and our witnesses' testimony. And with that I yield back.

Mr. WILSON. Thank you very much, Mr. Langevin.

And as indicated, we are having votes on the floor at this time. There are four votes. There will be, sadly, a significant delay. But we are recessed.

[Recess.]

Mr. WILSON. Ladies and gentlemen, I would like to welcome everybody back to a meeting of the Emerging Threats Subcommittee on the House Armed Services Committee. We have recessed for votes, and the votes are concluded. And we can proceed. And I would like to remind every one of our witnesses that your written statements will be submitted for the record. So that we ask that you summarize your comments in 5 minutes or less. Thank you for being here today. We will begin with Dr. Zacharias.

STATEMENT OF DR. GREG L. ZACHARIAS, CHIEF SCIENTIST OF THE UNITED STATES AIR FORCE

Dr. ZACHARIAS. Chairman Wilson, Ranking Member Langevin, members of the subcommittee, thank you for the opportunity to provide testimony on how the Air Force is advancing science in autonomy and the acceptance of the autonomy for future defense systems. I deeply appreciate your devoting time to this topic.

Just as a little addition to my background, I have been working in the manned machine area for over 40 years, first helping to design the space shuttle autopilot, later working with flight simulation, and most recently, with systems providing computational intelligence to help humans make better decisions.

The current focus on autonomous systems calls on many of these technology areas, and I am delighted to be in the middle of it right now in my current role as chief scientist. I hope I can help explain today some of the issues involved in development of these systems.

In the Air Force's vision for autonomy in future systems, we seek the right balance of human and machine teaming to meet future operational challenges by combining increasingly capable hardware and software systems with unique human abilities in perception, judgment, and innovation. The goal is to have human autonomy teams operate effectively in high tempo, uncertain, and complex decision environments where humans and machines can work together effectively, efficiently, predictably, and robustly. Boiled down to its essentials, the Air Force's autonomy, science, and technology vision is intelligent machines seamlessly integrated with humans maximizing mission performance in complex and contested environments.

So as machine capabilities advance, the Air Force's technology development approach is to keep the airmen at the center of the system design. Likewise, the Air Force's operational vision is to keep the airmen at the center of the critical decisions that occur throughout a mission and engagement. The ultimate goal is to ensure effective teaming of the airmen with the autonomous system for better agility, effectiveness, and mission success.

Embedded in this vision are three strategic objectives, if you will. First, the development of sensors and data-gathering technology that can provide the needed information for a system to better understand its operating environment and mission goals. Basically, the context. Second, the development of reasoning systems and software environments to assess situations to make recommendations or decisions. The computational intelligence part of it, if you will. And then finally, the refinement of different ways for carrying out those recommendations and decisions, whether through direct action, such as guiding an unmanned platform, or through recommendations to another human or a machine teammate. The overall goal here is to enable systems to react appropriately to their environment and perform situationally appropriate tasks, synchronized and integrated with other autonomous human or machine systems.

The payoffs include a greater ability to prevail in increasingly tested environments over greater ranges and time spans; protection of airmen from dangerous and harsh environments while increasing their mission effectiveness; reducing the time to conduct time-critical operations, such as in defending our air, space, and cyberspace assets against high tempo threats; providing increased levels of reliability, persistence, and resilience; and then, finally, reducing manning costs, as was mentioned earlier.

In your invitation to me to testify, you asked me to comment on how the Air Force has implemented the recommendations of the 2012 Defense Science Board Autonomy Report. And I hope that be-

tween my written statement provided earlier and my comments here today, I will have demonstrated that the Air Force has been very responsive to the DSB recommendations, and is leading the way in terms of autonomy research and use of autonomous systems.

Thanks for letting me speak on this exciting topic and for your interest in this game-changing technology. I look forward to answering any questions you may have.

[The prepared statement of Dr. Zacharias can be found in the Appendix on page 22.]

Mr. WILSON. Thank you very much, Dr. Zacharias. And, indeed, it is game changing. And I appreciate your enthusiasm and recognition of how important what you are doing. Thank you very much.

Dr. ZACHARIAS. Thank you.

Mr. WILSON. Mr. Kelley.

STATEMENT OF FRANK KELLEY, DEPUTY ASSISTANT SECRETARY OF THE NAVY FOR UNMANNED SYSTEMS

Mr. KELLEY. Chairman Wilson, Ranking Member Langevin, and distinguished members of the subcommittee, thank you for the opportunity to speak with you today. It is my pleasure to testify this morning beside my Army and Air Force counterparts as the Navy's first Deputy Assistant Secretary of the Navy for Unmanned Systems.

I would also like to thank Mr. Gates for coming down and seeing us at the Pentagon. Really appreciate that. And it is not lost on me, gentlemen, that in my past life, I would find comfort being flanked by two Ph.D.s, and have grown accustomed to the safety of such intellectual supervision. So thank you, gentlemen, for doing that for me.

Unmanned and autonomous systems are going to transform the future of how we operate as a Navy and as a military. However, unmanned technology will not diminish the importance of our most fundamental asset, our people. Instead, unmanned and autonomous systems which allow us to exceed human limitations will be used as powerful force multipliers across our fleet. Using autonomous systems in roles for which machines are best suited allows us to strategically employ sailors and marines for roles in which people are best suited.

The research and development work the Navy and Marine Corps is conducting to improve our autonomous capabilities for future military systems is impressive, from the early research in cooperative behavior to autonomous takeoffs and landings of our unmanned aircraft. These innovations in autonomy, however, need to be nurtured and introduced in a manner which will gain the trust of our sailors and marines, and the public we are here to protect.

I hope the committee will come to appreciate the deliberate and disciplined nature in which the Navy and Marine Corps are investing time and resources in the development and experimentation with this technology.

It is also important to understand that realizing the vision of a fully integrated unmanned and manned naval force will depend as much on significant military cultural evolution as on the tech-

nology innovation. We have to change the way we think to evolve the way we fight.

The strong leadership within the Navy today is laying down the foundation that will allow us to realize the vision of a fully integrated future force.

This past April, the Secretary of the Navy announced that he was creating a new organization to focus and guide the Navy's efforts on unmanned systems under the strong leadership of the Assistant Secretary of the Navy for Research, Development, and Acquisition, in order to create the Office of the Deputy Assistant Secretary of the Navy for Unmanned Systems, and to bring together all the many stakeholders and operators who are currently working on this technology in order to streamline their efforts.

Additionally, a new resource sponsor was established under the Chief of Naval Operations. OPNAV [Office of the Chief of Naval Operations] N–99, or unmanned warfare systems, was created so that all aspects of unmanned in all domains will be coordinated and championed. As of the 2nd of November, both organizations have been officially stood up and populated with highly qualified individuals from across our Navy and Marine Corps. Prior to our official establishment, the groundwork commenced over the summer, and the two organizations have collaborated with the DASN [Deputy Assistant Secretary of the Navy] for Research, Development, Test, and Evaluation [RDT&E] to develop a cross-Department prototyping and experimentation approach that embraces innovation.

To work rapidly to harness the potential of unmanned technology into deployable systems is built upon the incredible foundation laid by our Office of Naval Research [ONR] and the Naval Research Laboratory. These two organizations have a rich history of basic and fundamental research in autonomous and unmanned systems conducted by world-class personnel in world-class facilities.

However, despite the ample research that has been done, and despite the claims of some, autonomy is not a solved problem. There is much work to be done before we can realize our vision of a fully integrated manned and unmanned force. Autonomy still provides a host of unique challenges. Furthermore, autonomy alone will not ensure a secure America. We must understand the limits of autonomy, and, in so doing, come to more fully appreciate the advantages of being human.

In this way we will be able to build an effective teaming relationship between people and autonomous systems. The development of trust within this team will be critical to the success of all of our missions. We have a moral imperative to equip our sailors and marines with the best capabilities to do their missions. However, we also have a moral imperative to ensure that in addition to the technology innovation we develop an ethical, legal, and policy framework for how we will employ unmanned and autonomous systems.

Even as we carefully and deliberately build this framework, we also recognize that we have to be able to robustly defend against adversaries who do not play by our rules. Unmanned and autonomous technology will transform the way we operate. Your Navy and Marine Corps are committed to understanding and forging an

effective relationship between man and machine that will unlock our full potential of both.

Chairman Wilson, Ranking Member Langevin, and distinguished members of the subcommittee, thank you again for the opportunity to speak with you today. And I look forward to answering your questions.

[The prepared statement of Mr. Kelley can be found in the Appendix on page 38.]

Mr. WILSON. Thank you, Mr. Kelley. And we appreciate your prior Marine service, too.

We now proceed to Dr. Bornstein.

STATEMENT OF DR. JONATHAN BORNSTEIN, CHIEF, AUTONOMOUS SYSTEMS DIVISION, VEHICLE TECHNOLOGY DIRECTORATE, ARMY RESEARCH LABORATORY

Dr. BORNSTEIN. Chairman Wilson, Ranking Member Langevin, and other distinguished members of the subcommittee, thank you for the opportunity to speak with you about the research and development work currently being pursued by the Army to improve autonomy capabilities for future military systems. The recently published Army Operating Concept notes that the application of emerging autonomy technology creates the potential for affordable, interoperable systems that improve the effectiveness of soldiers and units. That document provides vision that, quote, “Autonomous and semiautonomous operational capabilities may increase lethality, improve protection and extend soldiers’ and units’ reach,” unquote. The Army Training and Doctrine Command [TRADOC], together with the Army’s science and technology, acquisition, and test and evaluation communities, is developing the robotics and autonomous systems strategy to implement this vision, creating a road map for autonomy technology development, materiel acquisition, and training for the next 30 years.

In his recent presentation at the Reagan Presidential Library, the Deputy Secretary of Defense noted that the autonomy—I am sorry—that autonomy technology has reached an “inflection point.” The technology is now being pursued widely. It is being pursued globally and by the commercial sector. There are differences, however, between the commercial and military application of this technology. Commercial usage generally focuses on benign, permissive, and structured environments. The military must design for adversarial, highly dynamic, and structured environments.

In the near term, the Army community has undertaken efforts to gain experience with these complex software systems. TRADOC Centers of Excellence have utilized the ongoing Network Integration Evaluation and beginning this fiscal year the Robotics Enhancement Program to place surrogate experimental autonomous systems in the hands of soldiers. Such experimentation will inform and aid development of future requirements, doctrine, tactics, techniques, and procedures required to effectively employ this new capability.

For the mid and far term, the science and technology enterprise’s efforts are focused on seven main thrusts. It is focused on the maturation and demonstration of advanced unmanned—I am sorry—advanced manned/unmanned teaming for both air vehicles and

ground vehicles to permit unmanned assets to serve as wingmen to manned elements of the force. It is exploring the effective teaming of unmanned air and ground vehicles. It is developing robotic technologies and capabilities that will enable unit resupply and sustainment operations using optionally manned and unmanned vehicles, and it is developing the cognitive decision tools for effectively commanding teams of advanced unmanned systems.

In addition, it is conducting research focused on creating the technology to seamlessly integrate unmanned elements, both air and ground, into small unit teams, and research to enable the development of swarms of unmanned systems capable of effectively conducting military missions at range. Taken as a whole, these efforts will provide the underpinnings for autonomous systems that can operate side by side with our soldiers on the battlefield in applications ranging from resupply to reconnaissance.

Although the autonomy technologies available today work well for the sets of conditions for which they were designed and tested, they lack the flexibility and adaptability that would enable them to work well for other situations. Systems using today's technologies must be teamed with humans to supply the cognitive capability required for complex missions, while the unmanned components of the force performs repetitive or persistent tasks. Significantly advancing autonomy technology, taking machines from tool to teammate, will require technology advancement beyond what is available today.

In conclusion, once again, I would like to thank Chairman Wilson, Ranking Member Langevin, and the other distinguished members of the committee for the opportunity to discuss the Army's role in pursuing autonomous capabilities for future military systems. The Army is committed to developing autonomous systems that can, one day, work side by side with our soldiers. I look forward to your questions.

[The prepared statement of Dr. Bornstein can be found in the Appendix on page 52.]

Mr. WILSON. Thank you, Mr. Bornstein. And with three sons serving in the Army, I want you to be very successful.

And we now will proceed to 5 minutes of questioning by each member of the panel. And fortunately we have Kevin Gates as our staff person who is very strict on maintaining the 5-minute rule, beginning with me.

And so we will begin with Dr. Zacharias. You mentioned in your testimony the concept of autonomy at rest. Could you explain that in more detail for the members so we can better understand what is important?

Dr. ZACHARIAS. Yes, sir. Yes, sir. And I should give credit to Dr. Craig Fields, the past director of DARPA [Defense Advanced Research Projects Agency], for—that is where I heard the phrases originally, but the notion is that we tend to think of autonomy in motion because of the RPAs [remotely piloted aircraft] and the UAVs [unmanned aerial vehicles] that we recognize, or Google's cars, or the Navy's unmanned underwater vehicles. And so all these systems, these autonomy in motion systems, have sensors or databases that tell them what is going on in the environment, like a GPS sensor, a global positioning sensor for an RPA position. They

also have onboard some kind of smarts, autonomous smarts that—embedded in an onboard computer that tells it how to act based on, say, an objective to fly from one way point to another.

And then they also have some sort of motor or locomotion subsystem that allows it to move around in its environment. And this could be for an RPA, a remotely piloted aircraft, the throttle or the ailerons or the control system. So while the sensors are very important to these systems and the motor parts are very important, the real advances in autonomy are happening in the middle part, the brain part, the onboard smarts. So if you think about removing those onboard smarts to a ground-based system, and putting them, say, in a command and control center or a planning center, then you have got autonomy at rest. So many of the advances that we are going to see in this area are—may come from data feeds or other sensors or satellite imagery, but they are going to be in these ground-base situations. And they will have a sense part and a think part and an output part. It might be a natural language generator like a SIRI [Speech Interpretation and Recognition Interface] interface or a visualization. But once you have done this, you have converted an autonomy in motion system to an autonomy at rest system.

So our community right now is beginning to realize that autonomy is not limited to systems that move about or locomote, but they are also very useful in decision-aiding systems, visualization systems, and so forth. And we can multiply the effectiveness of a lot of—if we could go to a modular approach, we could use one module in other areas, and we may also gain some efficiencies in test and validation as well. I hope that helps explain.

Mr. WILSON. And thank you very much.

And, Dr. Bornstein, in your testimony you mentioned commercial usage for some autonomy technologies. Where do you see the military driving technology development? And where do you see you will be to draw from the commercial sector for needed technologies?

Dr. BORNSTEIN. Sir, in my testimony I also mentioned that commercial applications tend to work in structured environments where there is less dynamicism. So despite what you might think about driving on the highways today, there is structure in the highway system. The Google cars, the Uber taxis, those are applications which are dealing with structure.

The military, however, is dealing with the dynamic environment, one that where we don't know things in advance. We have to have organic sensing and reasoning powers onboard the vehicle. So there is a distinct difference there. Where the military can leverage heavily is for those applications that are in more structured environments. Think in terms of logistics, many aspects of convoy operations, forward operating bases. Those are all items where there is structure, where there are commercial entities that are involved with development of systems, and the Army can leverage those capabilities. Or I should say the services can leverage those capabilities. I apologize.

Mr. WILSON. Well, thank you very much.

And, Mr. Kelley, the Navy has a unique challenge, and that is air, land, or sea operation. Would you describe some of the tech-

nical challenges specific to autonomous systems for each of the domains?

Mr. KELLEY. Thank you, sir. And that is true, that we do note that we operate in all domains and simultaneously in many cases. I was reminded today by Dr. Schuette, who is the director of research at ONR, that one of the ways to overcome some of the challenges is to start our S&T [science and technology] and make most of our S&T investments in domain agnostic and also platform agnostic. So that is one way that we are going to approach that.

If I can just real quick, I spent a lot of my time as a young guy doing electronic warfare, and I was told it was one of the toughest missions that you would ever participate in. Complex, dense, can be very confusing. It requires quite a bit of training. Not until I got exposed to what it was like in the mine and undersea warfare of how cluttered that environment is did I come to appreciate that my electronic warfare environment might be the number two most complex combat environment.

The way that that is also compounded is that the things we take advantage of in—when you operate above the surface, ability to communicate in the clear, taking advantage of things like the GPS, are not available to you. So these are going to be really big challenges for the Navy, particularly communication underwater and our precision navigation solutions that will provide to those solutions.

Mr. WILSON. Well, thank you very much. And Mr. Gates is again very precise. My time is up.

Mr. Langevin.

Mr. LANGEVIN. Thank you, Mr. Chairman. And I want to thank our witnesses for your testimony today.

So to all of our witnesses, what policy and operational concept issues at the tactical and strategic level are most pressing and must be addressed before deployment of more capable autonomous systems? For instance, the unmanned aerial systems concepts of operations requires an operator for takeoff and landing, and airspace restrictions of the U.S. impede testing and training. Integration into the airspace is still an issue, and systems must be able to detect, sense, and avoid. But this is not unique to air, of course.

So, Secretary Kelley, do you want to start from the Navy's perspective?

Mr. KELLEY. Certainly, sir. Thank you. You have listed off quite an array of challenges. One thing that I would like to mention. When I had a chance to get a hint that the Secretary was going to stand up a Deputy Assistant Secretary of the Navy for Unmanned Systems, one of the first places that I went to was an association called AUVSI, the Association of Unmanned Vehicle Systems International. They had tagged on the "I" on that point. I had a chance to talk to the president and CEO [chief executive officer] of AUVSI, a gentleman by the name of Brian Wynne, who did not spend any time in the military. And one of the things that we quickly found out in our dialogue was that we have many of the same problems. And so here is an organization not necessarily associated with DOD that is willing to team with us within the defense sector to solve some of these issues that you mentioned, sir,

like the airspace issues, the sense and avoid issue. So there is a great opportunity, I think, to team with the commercial sector.

I think one of the other areas that, if I can think back in my own time. Back in the day as a young guy in flight school, sometimes systems were not as reliable as we see our systems today. And so sometimes you would be in the cockpit and you would just pray to God that a piece of gear was actually going to function. I think some of the young people today take that for granted. The reliability of our equipment today is unprecedented. They don't question the fact that it is going to work. I think what I am finding today that is remarkable is, that our young people are really concerned about the ethical and moral implications of how these unmanned systems are going to be used.

This will also help us in getting the trust that I spoke about in my oral statement of our sailors and marines. The trust issue is sort of an implied task. We do have DOD directives that talk about certainly weaponizing platforms, but I think the biggest issue is sort of an intangible, and it is this ethical and moral element of what it means to put unmanned systems in combat.

Mr. LANGEVIN. Okay. Other panelists? Anybody else want to comment?

Dr. BORNSTEIN. I will make one off-the-cuff statement if—and one of the things that I see in the commercial sector is the issue of responsibility. We talk about an unmanned system. So if there is an accident in the national airspace or an accident on the road, who is liable for the action? As was just mentioned by my colleague, Mr. Kelley, we talked about—he talked about the ethical responsibility that many people see in the use of unmanned systems.

Will the liability for their use, will the responsibility of their use, who will that fall upon? That is a personal opinion that it will be a major issue in the future going forward both for the commercial sector and for the military sector.

Mr. LANGEVIN. That actually kind of touches on my next question. You kind of beat me to it there. But, again, I will pose it to the other members of the panel.

As I mentioned in my testimony, command and control becomes more challenging as systems become more autonomous. So how will you address chain of command as systems become more autonomous, particularly when you are talking about lethality in systems?

Dr. ZACHARIAS. Maybe I can start on that. This is a little out of my scope since I am on the S&T side. But I think, as Mr. Kelley said, I think much of it has to do with trust and proficiency. So one of the things is to try and design trust into these systems, including engineering the system so it performs well within its scope of operations, knowing when it is exceeding its scope of operations or the human operator knowing that, making sure they are knowledgeable of mutual understanding of their goals if they are working as a team or their sub tasks, and providing for natural interfaces. Transparency and explainability of their systems. It may be better to not have them be optimum, but rather be adequate and be able to explain what they are doing.

And, finally, training and practicing together just like any team would win. And, finally, I think the notion is that if you can get

these systems to codevelop concepts of operations and organizational design. I think the basic issue we are not going to just throw things over the transom and expect them to be perfectly integrated into the organization. And I think concepts will be codeveloped with the technology.

Mr. LANGEVIN. Mr. Kelley, do you have anything to add?

Mr. KELLEY. Yes, sir. Thank you. I really—one of the great things about coming to hearings like this is you learn so much. And I love the phrase of "codevelop." I just had a chance to sit down with the PEO [Program Executive Officer] for C4I [Command, Control, Communications, Computers, and Intelligence] for the Navy, Admiral Chris Becker, and we were talking yesterday about the organizations that provide the infrastructure, so the C2 [command and control junction] nodes, the network, the com pipes. How important it is to get with those organizations quickly. Because that can bring a concept of operations down to its knees even though that you have the, you know, the finest autonomous system, the autonomous platform that, you know, that the, you know, greatest engineers in the world could have designed.

I also think when we start coming up with what are those essential elements of information that a commander, and at the end of the day, it is going to be a commander who is going to be held accountable for how these systems are used, what are those elements of information that they are going to need in order to exercise judgment. We have got to come up with these priority schemes, a way to make sure that that kind of information and data gets to the commander on the scene.

Mr. LANGEVIN. Very good. Thank you. And I yield back, Mr. Chairman.

Mr. WILSON. Thank you, Mr. Langevin.

We will now proceed on a second round. We really appreciate you being here today, each of you.

For each of you, beginning with Dr. Zacharias, how are you drawing on or integrating technology efforts being funded by industry through their internal research and development process or from international S&T efforts being funded through foreign governments' science funding agencies?

Dr. ZACHARIAS. Thank you, sir. Well, let me start with the international efforts first. So we are exploring agreements with international partners, collaborative technical exchanges. The Air Force Research Lab has agreements out with—a multilateral agreement under—there is a technical cooperation effort with the U.K. [United Kingdom], Australia, New Zealand, Canada, and working on the grand challenge in autonomy research. And we are also participating heavily in the V&V [verification and validation] issues because eventually if we are having coalition operations, we will have these systems working with one another, and they will have to be cooperating, clearly.

So on the commercial side, we are working with the DIUx [Defense Innovation Unit Experimental] out in the—I apologize. I can't remember what it stands for, but the DOD initiative out in the West Coast, Silicon Valley, to try and work with some of the folks that are doing some of the advance technologies in machine learning, pattern recognition, robotics, and so forth. And we will be

reaching out additionally with more Air Force Research Lab personnel in that direction.

Mr. WILSON. Thank you. And Mr. Kelley.

Mr. KELLEY. So I think one of the responsibilities of our office is also to work across the entire enterprise and provide opportunities for industry to participate in demonstrations and exercises. Even though we have been in combat in Afghanistan, I think that the Marine Corps and the Office of Naval Research can be very, very proud of a program that was started a while back.

I can't exactly remember when it was. But it was in terms of an unmanned logistics UAV that would deliver, you know, cargo out on the battlefield. And to date, the cargo UAV was able to deliver, you know, over—could have the potential to deliver over 6,000 pounds of cargo a day. Transitioning that into, you know, more formalized programs like AACUS, the autonomous aerial cargo utility system, a K–MAX bird [helicopter]. I think that that is an important opportunity for industry to be able to demonstrate their understanding of what the environment is like.

I already described our association with AUVSI. We did have a chance in October to speak. It was the first time we could speak as an organization at their AUVSI defense. And I see many people sitting behind me that were actually there as well, both Army and Air Force. And it was a great opportunity for folks to actually show what was going on, in not only commercially, but in each of the services.

Mr. WILSON. Thank you very much.

And Dr. Bornstein.

Dr. BORNSTEIN. Like the other services, the Army maintains bilateral arrangements with many countries through the TTCP [The Technical Cooperation Program], the Five Eyes, through countries such as France, Germany, Israel, where we try to develop programs of common interest. In addition, my own organization, the Army Research Lab, has embarked upon a new initiative over the course of the past 2 years that we call Open Campus, which is focused not on giving contracts to companies but rather developing cooperative research and development agreements where there is a mutual interest on the part of both parties.

Letting small business who are usually the furnaces of innovation and technology come to our site to utilize DOD facilities to further what they are doing together with researchers from the laboratory. We do similar activities with other organizations throughout the Army, and we invite the other services to participate as well.

Thank you, sir.

Mr. WILSON. Thank you very much. And for anyone who would like to answer, what defenses exist to protect autonomy technologies from being hacked, resulting in losing control?

Mr. KELLEY. I will take a stab at it, sir. And I think one of the most important things here is a new testing paradigm for autonomous systems that would lean heavy on the cyber side of the house I think is the most critical piece.

Now, one of the challenges, I think, with autonomous systems is that it becomes very challenging to try to test all of the possible scenarios that you could possibly encounter. And so we will have

to work through that. But the VV&A, the verification, validation, and accreditation of these systems and, of course the accreditation will also will have a cyber element to it means that, you know, that we have been able to test and make sure that, you know, that it can't be hacked into and taken over.

Mr. WILSON. We just wish you the best addressing, sadly, people who have such ill intent, as we see every day in the world.

We will now proceed to Mr. Langevin.

Mr. LANGEVIN. Thank you, Mr. Chairman. And as usual, the chairman and I are very much on the same page on asking these kinds of questions. And I wanted to get to the cyber question or the security question as well. Just to build on that, if you could elaborate, what role do trusted foundries and third party manufacturer agreements play in the security?

Dr. ZACHARIAS. I will take a stab at that one, too. So my understanding is, what role will trusted foundries and supply chains?

Mr. LANGEVIN. Yes.

Dr. ZACHARIAS. Clearly it will be, I think—we are planning an upcoming study on looking at issues that Mr. Kelley raised both in terms of embedded systems, reliability, and authority authenticity, if you will. Coms links, vulnerabilities. Because in terms of over and above—vulnerabilities over and above our normal embedded systems, which we also have those issues of coms links and cyber vulnerabilities, and there are efforts ongoing. I am not intimately familiar with them, but in terms of establishing trusted foundries now, and certainly many more regulations, say, going out to industry in terms of protecting government IP [intellectual property] and making sure that outsiders don't exfiltrate our designs and compromise our embedded systems.

In fact, there was a large summer study, excuse me, by the Science Advisory Board for the Air Force this summer looking specifically at embedded systems' vulnerability. And clearly that will have an impact on autonomous systems.

Mr. LANGEVIN. Thank you.

To all of our witnesses, the Defense Science Board identified transition or lack thereof as an obstacle for utilization of autonomous capabilities. What steps are you taking to improve transition of technologies?

Dr. BORNSTEIN. I will start. In my opening remarks, I mentioned ongoing activity looking at near-term applications of the technology. Those are key and critical to transition and adoption by the force. As I have said many times, it is very difficult to write requirements for a revolutionary technology in which you have no experience. The use of those activities is to try to build that experience base on the operational, the training and doctrine community, so they can begin to build the requirements, the techniques, tactics, and procedures that will ultimately be used and facilitate the transition of technology in that way.

Mr. LANGEVIN. Okay. Mr. Kelley.

Mr. KELLEY. Thank you, sir. So also within the DSB 2012 study they also talked about the autonomous reference framework, which in my discussions with folks at ONR, they are very receptive to that concept. And actually, when I think about it, it makes a lot of sense.

It is the three level—a cognitive level, a mission level, and a complex—complex systems trade space level. So that goes right to the heart that I think that Dr. Bornstein was talking about in terms of the design of these systems.

In the Navy right now we—with the stand-up of DASN Unmanned Systems and the renewed emphasis of DASN RDT&E to energize a naval research development enterprise, and with the stand-up of OP 99, our resource sponsor, we are taking a really rigorous stab at prototyping and experimentation. And this is to better inform the requirements at the front end of our acquisition framework. And so the most important thing here is to get the requirements right.

So what we envision is that this will be an iterative cycle constantly going back to the warfighter in terms of making sure that we got those requirements right.

Mr. LANGEVIN. Thank you.

Dr. ZACHARIAS. And if I could follow up, my colleagues covered most of the points, I think. I think this is—again, I think the Air Force has learned a lot with its RPA experience being the lead service in establishing so many thousands of hours of operation in that area. And it has led to a change in operations and how they are used and issues to do with manning and manpower.

And it has also raised other issues going from how do you pilot these things to actually how you process the information, the thousands of hours of video that you get off of them. And so they raise other areas and opportunities for autonomy.

And one last thing I would say, these will be again codeveloped and embraced more fully with good human systems integration technologies. Again, I think something Mr. Work mentioned a couple weeks ago, how you get these systems to work closely with humans and make them more understandable and reliable and trustworthy, appropriately trustworthy. You don't want to encourage trust where it isn't deserved.

Mr. LANGEVIN. Okay. Very good. And I guess to all of you, you've touched on it a little bit already, but how well are you coordinating your autonomous systems investment strategies in lessons learned across the services?

Mr. KELLEY. I'll try. So I think that is the reason—I don't think, I know—that is the reason why our office was stood up, to be quite honest. And one of the things that is different about the DASN for unmanned shop is I have counterparts within the Assistant Secretary of the Navy for Research, Development, and Acquisition, other DASNs. And if you could sort of picture them as being vertically oriented within a domain. Say DASN air, guy by the name of Gary Kessler is DASN air. Gloria Valdez, DASN ships. They have the whole portfolio of those particular platforms, air and ships.

In our shop we will be cutting across. We will be cutting across, essentially generating and now supervising, providing oversight, managing a portfolio of just unmanned systems and how that fits into the broader naval operational concepts.

Dr. BORNSTEIN. I would be remiss if I didn't try to answer that question since I am currently acting as the lead for the Autonomy Community of Interest [COI] within OSD [Office of the Secretary

of Defense]. And Larry Schuette is my deputy sitting behind me there. OSD basically recognizes that there needs to be coordination among all the services. It is part of Reliance 21. And ideally the community of interest should be a forum where subject matter experts can get together and really begin to understand not only what each other are doing, but have the opportunity to cross-fertilize thoughts and concepts concerning the technology.

Next Wednesday the Autonomy COI will hold a workshop at ONR, really bringing together a large number of people to discuss three topics: modeling and simulation; test and evaluation, verification, validation; and trust in automation. And those will be three topics. Community members will be there talking about it. I can't tell you what will come out of it, but I almost guarantee that there will be some cross-fertilization, and it will be agnostic, service agnostic, in that regard. So there is that definite thrust towards cross-fertilization among all the services, at least at the S&T level.

Mr. LANGEVIN. That is encouraging. Thank you.

Well, if nothing else on that, I will thank our witnesses and I will yield back. I have additional questions I will submit for the record, but thank you, Mr. Chairman.

Mr. WILSON. Thank you, Mr. Langevin. And thank each of you for being here today and in the future. I am very, very grateful, Kevin Gates has been a lead on this. He has actually been working in this field for many years. And I am really grateful for his professionalism, and we look forward to hearing and working with you in the future.

And with that in mind, we are adjourned.

[Whereupon, at 12:26 p.m., the subcommittee was adjourned.]

A P P E N D I X

NOVEMBER 19, 2015

PREPARED STATEMENTS SUBMITTED FOR THE RECORD

NOVEMBER 19, 2015

Chairman Wilson Opening Statement

Advancing the Science and Acceptance of Autonomy for Future Defense Systems

19 November 2015

Ladies and gentlemen, I call this hearing of the Emerging Threats and Capabilities subcommittee to order.

I am pleased to welcome everyone here for today's hearing on advancing the science and acceptance of autonomy for future defense systems. The military necessity for autonomous systems is obvious. Many of us recognize that our military is not large enough, and it is not likely to grow sufficiently over the next few years to handle all of the threats we face. On top of this, shrinking budgets will shrink our military, stretching our men, women and platforms even further to be able to accomplish their ever-changing missions.

The promise of autonomous systems is becoming more evident every day. From self-driving cars to smart buildings to the increasing presence of robotics—the full potential of autonomous systems is nearly endless. What is less understood are the technical and policy challenges that must be identified and solved to make those visions a reality. Most of us are more likely to understand what is possible with examples provided from TV and movies, so I am looking forward to having real experts shed light on what the actual state-of-the-art technology is, and what the path to acceptance looks like for the military services.

With that as a backdrop, we look forward to hearing from today's panel of witnesses who will help educate members on many of these issues related to autonomy research and the development of increasingly autonomous systems.

Our witnesses before us today are:

Dr. Greg L. Zacharias
Chief Scientist of the U.S. Air Force

Mr. Frank Kelley
Deputy Assistant Secretary of the Navy for Unmanned Systems
(DASN US)

Dr. Jonathan Bornstein
Chief, Autonomous System Division, Vehicle Technology
Directorate, Army Research Laboratory

I'd like to turn now to my friend Mr. Jim Langevin from Rhode Island for any comments he'd like to make.

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UNITED STATES HOUSE OF REPRESENTATIVES

DEPARTMENT OF THE AIR FORCE

PRESENTATION TO THE HOUSE ARMED SERVICES COMMITTEE
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES
U.S. HOUSE OF REPRESENTATIVES

SUBJECT: Advancing the Science and Acceptance of Autonomy for Future Defense Systems

STATEMENT OF: Dr. Greg L. Zacharias, SES
Chief Scientist of the Air Force

November 19, 2015

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Introduction

Chairman Wilson, Ranking Member Langevin, Members of the Subcommittee and Staff, I am pleased to have the opportunity to provide testimony on how the Air Force is advancing the science and acceptance of autonomy for future defense systems.

The importance of autonomy to the Air Force and its future systems was emphasized in 2014 when the Secretary and Chief of Staff of the Air Force published *America's Air Force: A Call to the Future*. In laying out a vision for the next 30 years, the United States Air Force strategy places an emphasis on the development of autonomous systems as a means of achieving strategic advantage in future operations. This includes the development of sensors and data gathering technology that can provide the needed information for a system to better understand the operating environment and mission goals, the development and implementation of reasoning systems and software environments to assess situations and make recommendations or decisions, and the refinement of different means for effecting those recommendations/decisions, whether through direct action, such as guiding an unmanned platform, or through recommendations to another human or machine teammate. The overall goal is to enable systems to "react to their environment and perform more situational-dependent tasks as well as synchronized and integrated functions with other autonomous [human or machine] systems". The document also recognizes autonomy's promise to lower system manning costs while making human operators more effective in their missions, increase the range of operations by extending manned capabilities while simultaneously protecting them from harsh or dangerous environments, reducing the time required to conduct time-critical operations, and providing increased levels of operational reliability, persistence, and resilience.

This past summer, my office published the first volume of *Autonomous Horizons: System Autonomy in the Air Force, Volume I: Human Autonomy Teaming*. Authored by my predecessor, Dr. Mica Endsley, this report describes a vision for autonomous systems that work synergistically with our airmen as a part of an effective human-autonomy team in which goals are shared, common situation awareness is maintained, and mission tasking responsibility flows smoothly, simply, and seamlessly between them. In this vision of the future, autonomous systems will be designed to serve as a part of a collaborative team with airmen where flexible autonomy will support the control of missions, tasks, platforms, and subsystems, in a dynamic fashion, sharing information, control, and tasking across humans and other autonomous systems, at different mission levels and over multiple phases or times within a mission. As envisioned, these systems will be able to operate robustly and in a predictable fashion, in uncertain and dynamically changing environments.

During my tenure as Chief Scientist of the Air Force, I plan to continue exploring this technically challenging area with the publication of two follow-on volumes to *Autonomous Horizons*. Volume II will explore nascent or existing science and technology (S&T) areas that can contribute to the creation of a level of perceptual and computational intelligence needed to support the vision described in Volume I, and that can deal effectively with the challenges of uncertainty and variability in "real-world" environments that include countering adversarial activities. Volume III will address key infrastructure needs for autonomous system development, including cyber security/reliability, communications requirements and network vulnerability, and command and control structures and systems. Working in concert with the Air Force Research Lab, I expect these volumes to provide detailed road maps for the basic and applied research and technology demonstrations needed to advance autonomy at across all levels of the Air Force.

As you are aware, six major recommendations were made in the 2012 Defense Science Board (DSB) report on the role of autonomy in DoD systems. The first recommended using a three-facet autonomous systems framework to guide autonomous system development and acquisition, while the second recommended a coordinated autonomous systems S&T effort across the services, in four Tier I areas: Machine Perception, Reasoning and Intelligence (MPRI), Human/Autonomous System Interaction and Collaboration (HASIC), Scalable Teaming of Autonomous Systems (STAS), and Test, Evaluation, Validation, and Verification (TEVV).[1] Because my focus is on S&T, the majority of my comments will focus on this second recommendation, and AFRL's contribution to these areas. However, at the end of this testimony I will provide additional comments related to the other recommendations.

The Air Force's primary agent for autonomy research, Air Force Research Laboratory (AFRL), commissioned the development of the AFRL S&T Autonomy Vision and Strategy in 2013. This document identifies the major goals, technical challenges, and investment strategies needed to discover, develop, and demonstrate warfighter-relevant autonomy S&T to maintain and enhance air, space, and cyberspace dominance. This strategy has been coordinated with the other services and with OSD through the Assistant Secretary of Defense for Research and Engineering's (ASD(R&E)) Autonomy Community of Interest (COI). A result of this coordination, the DoD Autonomy Roadmap, links directly to the key enabling autonomy technologies identified above and to Recommendation 2 of the DSB report (MPRI, HASIC, STAS, and TEVV).

[1] Dr. Jon Bornstein (Autonomy COI Lead), "DoD Autonomy Roadmap Autonomy Community of Interest", National Defense Industrial Association (NDIA) 16th Annual Science & Engineering Technology Conference/Defense Tech Exposition, 24-26 March 2015

Air Force Autonomy Research Program

In its vision for 2020, AFRL seeks to enable the right balance of human and machine capability to meet Air Force challenges in the future by focusing on growing autonomous system capability, integrated with the human capacity to perform in a high-tempo, complex decision environment, and optimized in a fashion that allows humans to work with machines effectively, efficiently, predictably, and robustly. Simply stated, the AFRL Autonomy S&T vision is:

Intelligent machines seamlessly integrated with humans - maximizing mission performance in complex and contested environments

As machine capabilities advance, AFRL's approach is to keep the airman at the center of the system design to ensure the end result is effective teaming of the airman with an autonomous system to enable greater agility, effectiveness (lethal or non-lethal), and mission utility. Embedded in the vision are the following strategic goals which support the ability to do collaboration and teaming between types of autonomous systems, as well as adjuncts to manned systems: 1) highly effective human-agent teaming will harness a system's ability to digest data and the human's ability to deal with uncertainties to improve human-system performance; 2) multiple autonomous systems will actively coordinate their actions to achieve the mission intent; and 3) systems with enhanced intelligence and self-governance will enable operation in complex, contested environments that create challenges exceeding human (-alone) performance limits. Achievement of these goals will provide the Air Force with autonomous system capabilities that enable greater resiliency, capability, and versatility.

We now describe some of the AFRL autonomous systems research and development efforts, on-going or planned, organized according to the four Tier I areas identified in the DSB 2012 study and which comprise the OSD COI Autonomy.

Machine Perception, Reasoning and Intelligence (MPRI) Research

AFRL has three research areas that directly support the Machine Perception, Reasoning and Intelligence (MPRI) area: mature machine learning, situational understanding of the contested environment, and robust system self-protection. Advancements in computational intelligence underpin a machine's ability to perceive, assess, reason, plan, decide, and act.[2] As a result, AFRL is actively performing research in artificial intelligence, cognitive and computer science, data analytics, and machine and human learning. While much of DoD's focus is in supporting "autonomy in motion" (i.e., in robotics and unmanned platforms), AFRL is also actively supporting "autonomy at rest" needs in the intelligence, surveillance, and reconnaissance (ISR) world. AFRL's Human Effectiveness Directorate has an ISR Analyst Test Bed which provides a research-representative Processing, Exploitation and Dissemination (PED) cell for developing interfaces and technologies. Outputs of this research, the Internet Relay Chat Coordinate Extractor (ICE) and Enhanced Reporting Narrative Event Streaming Tool (ERNEST), not only improve manpower efficiencies and reduce airman workload, but also lay the groundwork for integrated multi-INT autonomous processing and advance analyst cuing via autonomous decision-aiding.

Since autonomous systems must have the ability to anticipate, sense, and respond to dynamically-changing threats, AFRL is also developing technologies that enable situational understanding of the contested environment. This demands an ability of machines to combine and fuse from sensor cues, embedded domain knowledge, and a maintained situational awareness, and to modify their actions in preparation for (or in response to) a wide range of kinetic and non-kinetic threats. This capability is especially critical when autonomous systems

[2] Nikita A. Visnevski and Mauricio Castillo-Effen. "A UAS Capability Description Framework: Reactive, Adaptive, and Cognition Capabilities in Robotics", IEEEAC Paper #1259, Version 4 Updated December 3, 2008.

are expected to detect and respond to adversarial manipulation and deception in contested environments.

In addition, the autonomous systems must operate safely and competently when communication links with humans or other autonomous systems are broken or jammed. To ensure effective operations in an adversarial environment, AFRL is pursuing assured, secure, robust communication, surveillance, and navigation technologies. Specific areas of research in this area include GPS degraded/denied navigation for weapons, laser communication, and robust satellite operation in the presence of anomalies and threats.

Human/Autonomous System Interaction and Collaboration (HASIC) Research

A goal of AFRL's autonomy program is to deliver flexible autonomy systems with highly effective human-machine teaming. The keys to maximizing the human-machine interaction are: instilling appropriate levels of confidence and trust among the team members[3]; understanding of each member's tasks, intentions, capabilities, and progress; and ensuring effective and timely communication needed to support effective teaming. All of which must be provided within a flexible architecture for autonomy that facilitates different levels of authority, control, and collaboration, along the lines identified by the "cognitive echelon" described in the 2012 DSB Autonomous Systems Report (Recommendation 1). Targets for reaching this goal range from near-term analysis of cyber operator stress and vigilance indicators, to more long-term aspirations of trusted autonomy where thousands of adaptive collaborating autonomous agents team with humans.

The current integration of an Auto Ground Collision Avoidance System (Auto GCAS) into the Air Force's operational F-16 fleet is an example of how the focus on human-machine

[3] *Appropriate* is the key qualifier here, since overtrust of an underperforming system can lead to misuse and mishaps, while undertrust of a competent system can lead to disuse and inefficiencies.

teaming and the need to develop trust across the team can build acceptance of autonomous systems within the Air Force. The system was developed jointly by five organizations working closely together: AFRL; Lockheed Martin's Advanced Development Programs (ADP), also known as the Skunk Works®; the Office of the Undersecretary for Personnel and Readiness; NASA's Armstrong Flight Research Center; and the Air Force Test Center. The system has already been credited with saving the lives of two F-16 pilots (and their aircraft), by preventing a tragic accident called controlled flight into terrain (CFIT), which happens when a pilot, in full control of his or her properly functioning aircraft, inadvertently flies the aircraft into the ground.[4] One of the keys to acceptance of this Auto GCAS technology was a two-year study sponsored by AFRL's Air Force Office of Scientific Research (AFOSR) and its Human Effectiveness Directorate.[5] As the Auto GCAS system neared implementation in 2014, the study worked with test pilots, engineers, managers, and operational pilots to identify lessons learned from technology development, to determine real-world perspectives on trust evolution, and to examine potential influences on trust. These results are now being used by a follow-on field study is currently underway for the Air Force Flight Test Center, the F-16 System Program Office Safety Office, the Air Combat Command Safety Office, the AFRL Aerospace Systems Directorate, and the F-35 Collision Avoidance Technology Program. This four-year study plans to examine pilot trust in Auto GCAS, and the evolution of trust with continued experience with the system. The study will also identify and document user experience, concerns, impact, and benefits of the technology as they emerge, to provide a basis for understanding critical trust issues with more complex autonomous systems to be fielded in the future.

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[4] https://www.faasafety.gov/files/gslac/library/documents/2006/Oct/6583/AC%2061-134.pdf

[5] "Influence of Cultural, Organizational and Automation Factors on Human-Automation Trust: A Case Study of Auto-GCAS Engineers and Developmental History" in *Human-Computer Interaction. Applications and Services* (Volume 8512 of the series Lecture Notes in Computer Science), 2014.

Scalable Teaming of Autonomous Systems (STAS) Research

AFRL's Autonomy Research Program is focused on creating actively coordinated teams of multiple autonomous systems to achieve mission goals that are better carried out by larger teams of smaller disaggregated systems or platforms (commonly referred to as "swarms"). Advanced autonomous systems must be able, as individuals and as teams, to analyze their missions, goals, and responsibilities; and decompose them into actionable, individual tasks and functions. They must be able to dynamically organize into a team to effectively perform the mission tasks, efficiently allocate and use their collective resources in real-time, and communicate as necessary to replan and reallocate tasking as the mission or adversarial environment changes.

Air Force research in this area includes near-term goals of collaborative control of six or fewer autonomous platforms and space-to-space asset collaboration and cross queuing with more far-term goals of agile swarming weapons and large numbers of adaptive C2ISR collaborating agents. As an enabler to this research, AFRL is currently collecting proposals for a Low Cost Attritable Strike Unmanned Aerial System (UAS) Demonstration that will design, develop, assemble, and test a technical baseline for a high speed, long range, low cost, limited-life strike Unmanned Aerial System (UAS). The program will also identify key enabling technologies for future low cost attritable aircraft demonstrations, and provide a vehicle for future capability and technology demonstrations. The goal of this program is to establish a benchmark, concluding in a flight demonstration that will test the bounds of what can be accomplished in a short time to establish a baseline system cost against a notional set of strike vehicle requirements.

Test, Evaluation, Validation, and Verification (TEVV) Research

Test and evaluation and validation and verification (TEVV) is vital to maximizing the operational gains of advanced autonomy, but provides significant challenges over more traditional systems because of four key discriminators: 1) "high-functioning" autonomous systems will necessarily be complex software systems, capable of demonstrating unanticipated "emergent" behavior, and will suffer the key validation and verification (V&V) issue associated with such systems, notably an inability to exhaustively test operation under all foreseeable conditions; 2) autonomous systems interact with their environment, via sensors, effectors, and communications links, and the explicit specification of all combinations of the system inputs/outputs and environmental variables is combinatorially impossible; 3) autonomous systems will interact with human teammates at some level, so that real-time operator in- or on-the-loop experimentation will be necessary, thus limiting the dimensionality of the test space because of time/resource constraints; and 4) sufficiently high-functioning systems will evolve into systems that learn over time and scenario exposure, so that behaviors will change over time, necessitating retest and possible recertification as a function of system "experience." As a result, the TEVV working group of the DoD Autonomy COI, following the recommendations of the 2015 DSB Autonomy Study has adopted a "continuous/life cycle approach" to T&E.

Additionally, research is underway on alternative means of autonomous agent licensure similar to pilot or operator licensure vs. traditional certification approaches for non-autonomous components. AFRL is also developing methods for verification early in the design cycle (e.g., to formally validating requirements for consistency and completeness). Finally, AFRL is developing run-time validation techniques to ensure the system is operating safely and effectively during use, even if design-time verification is not complete due to system learning.

Air Force Response to 2012 DSB Report on the Role of Autonomy in DoD Systems

I now return to the recommendations made in the 2012 Defense Science Board (DSB) report on the role of autonomy in DoD systems, and the follow-on efforts made by the Air Force in that regard.

The first recommendation proposed the use of a three-facet autonomous systems framework to guide autonomous system development and acquisition. This is illustrated in Figure 1, and is comprised of three views: a cognitive echelon; mission dynamics; and trade space. In general, Air Force S&T efforts in this area espouse this framework, if not explicitly acknowledging its specific structure and nomenclature. In particular, the *cognitive echelon* view is used to parse many of the autonomous system development efforts, ranging from mission-level ("at rest") planning aids to help develop a mission, to section-level ("in motion") capabilities needed for collaboration of multiple autonomous platforms, to vehicle-level ("in motion") systems like Auto GCAS. The *mission dynamics* view is also embraced by AFRL efforts, since many of the efforts focus on individual portions of the mission (e.g., pre-mission planning, in-mission flight management, post-mission ISR processing). In addition, researchers have embraced the notion of flexible levels of autonomy (as described in *Autonomous Horizons Volume I*), in which those levels will vary, and task responsibility will change over mission phases, depending on a number of factors, such as operator workload, system competence, task tempo, etc. Finally, the *trade space* view can be viewed as simply good systems engineering, where systems attributes, such as optimality vs. robustness, are traded off in an iterative design-prototype-experiment-evaluate fashion to arrive at a compromise solution that accounts for wide variety of factors and characteristics that constitute a well-designed system that can be operated effectively and maintained efficiently. While this is normally the purview of the Air Force's

acquisition arm, the S&T community is well aware of the constraints that go into developing a successful weapons system through the use of an overarching system engineering process which includes the trade space view noted in the DSB report. In short, AFRL embraces the three-facet autonomous systems framework recommended by the 2012 DSB study.

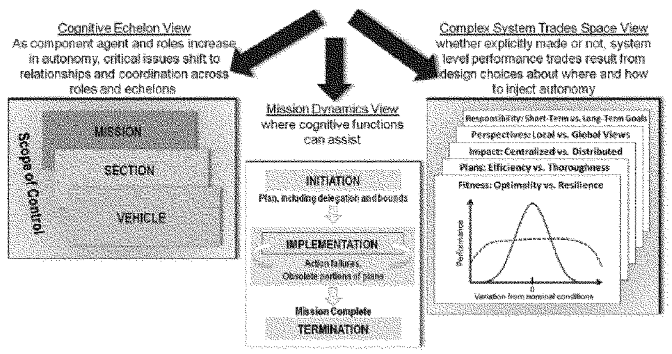

Figure 1: Framework for the Design and Evaluation of Autonomous Systems

The second recommendation proposed a coordinated S&T program guided by feedback from operational experience and evolving mission requirements. The Air Force is contributing to this in three ways. First, the Air Force has been and continues to be a strong and active member of the OSD Autonomous Systems COI and its four Tier I areas described earlier. The AFRL's current Chief Technology Officer, Dr. Morley Stone, was a previous Autonomy Community of Interest (COI) Lead and was instrumental in building a coordinated DoD roadmap for Autonomy research. AFRL members currently co-lead three of four of the COI's working groups. Second, as described earlier in the bulk of my testimony, AFRL, via its 2013 S&T Autonomy Vision and Strategy document, has explicitly laid out how it will support the major technology development recommendations made in the DSB Report and explicitly formulated in the Tier I areas of the Autonomy COI. Finally, in late 2013, under ASD(R&E)'s Reliance 21 initiative, DoD allocated

$15 million per year for three years to competitively fund autonomy projects run by the DoD laboratories. The Autonomy Research Pilot Initiative (ARPI) program selected seven projects, one of which is led by AFRL and is supported by the other services. The initiative's focus is on research and development for instantiating an "Intelligent Multi-UxV Planner with Adaptive Collaborative/ Control Technologies (IMPACT)" by combining flexible play-calling, bi-directional intuitive human-autonomy interaction, cooperative control algorithms, intelligent agent reasoning and machine learning technologies to enable cooperative multi-air/ground/sea unmanned vehicle missions.

The third recommendation proposed that acquisition programs emphasize the separation of the software from the platform hardware and the use of open software architectures. As these are ongoing efforts within the acquisition branch of the Air Force and not direct S&T efforts, I will refrain from commenting, except to note that the S&T community is aware of these acquisition goals and will support them as needed.

The fourth recommendation focused on addressing the unique challenges posed by autonomous systems for the developmental and operational test communities. As noted above, the Air Force S&T community acknowledges these challenges, and is directly supporting the Test, Evaluation, Validation, and Verification (TEVV) Autonomy COI Working Group, across multiple fronts: exploring concepts for "continuous V&V" throughout a system's lifetime as missions change and system experience grows, developing methods for model-based simulation and verification at all stages of development, acquisition, testing, and training ("the "digital thread"), and co-development of concepts of operations via extensive man-machine teaming.

The fifth recommendation focuses on using lessons learned based on the use of autonomous systems in recent conflicts, in professional military education, war games, exercises and

operational training. While not directly the purview of Air Force S&T, AFRL has a long history of working with remotely piloted aircraft (RPA) operators to address shortcomings in existing systems, particularly the Ground Control Stations of Predator and Reaper. This work has led to the development of new concepts for command and control of these and future systems like them. In addition, the S&T community's engagement in Future Games 2014 wargaming efforts (with operators) led directly to the publication of *Autonomous Horizons Volume I*.

Finally, the sixth recommendation encouraged the Defense Intelligence Agency (DIA) and the Intelligence Community to track adversarial capabilities with autonomous systems and the Services to include these threats in war games, training, simulations and exercises. As these are ongoing efforts within the Intelligence Community, I will refrain from commenting.

Conclusion

In conclusion, I hope that I have been able to convey to you the Air Force's progress in advancing the science and acceptance of autonomy in our future systems and the close coordination of our research portfolio with the other services through OSD's Autonomy COI. In addition, I am confident that I have demonstrated that the Air Force S&T enterprise has been responsive to recommendations from the 2012 DSB Autonomy Study.

On behalf of the dedicated scientists and engineers of the Air Force, thank you for the opportunity to testify today and for your continued support of United States Air Force science and technology. I look forward to answering any questions you may have.

Dr. Greg L. Zacharias
Chief Scientist of the U.S. Air Force

Dr. Greg L. Zacharias is Chief Scientist of the U.S. Air Force, Washington, D.C. He serves as the chief scientific adviser to the Chief of Staff and Secretary of the Air Force, and provides assessments on a wide range of scientific and technical issues affecting the Air Force mission. In this role, he identifies and analyzes technical issues and brings them to the attention of Air Force leaders, and interacts with other Air Staff principals, operational commanders, combatant commands, acquisition, and science and technology communities to address cross-organizational technical issues and solutions. He also interacts with other services and the Office of the Secretary of Defense on issues affecting the Air Force in-house technical enterprise. He serves on the Executive Committee of the Air Force Scientific Advisory Board. He is the principal science and technology representative of the Air Force to the civilian scientific and engineering community and to the public at large.

Dr. Zacharias served on the Air Force Scientific Advisory Board for eight years, contributing to nine summer studies, most recently chairing a study on "Future Operations Concepts for Unmanned Aircraft Systems." He also chaired the Human System Wing Advisory Group, was a member of Air Combat Command's Advisory Group, and served as a technical program reviewer for the Air Force Research Laboratory (in Human Effectiveness and Information Systems). He was a member of the National Research Council (NRC) Committee on Human Factors (now the Committee on Human-Systems Integration) for over ten years, supporting a number of NRC studies including one for Defense Modeling and Simulation Office evaluating the state-of-the-art in military human behavior models, and co-chairing a follow-up study entitled "Organizational Models: from Individuals to Societies," which presents a roadmap for future DoD science and technology investments in this area. He has served on the DoD Human Systems Technology Area Review and Assessment (TARA) Panel.

Prior to assuming his current position, Dr. Zacharias worked as a Research Engineer at the C.S. Draper Laboratory and a Senior Scientist at Bolt Beranek and Newman Inc. before most recently serving as the President and Senior Principal Scientist of Charles River Analytics, a research and development company that he co-founded.

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NRC Panel on Modeling Human Behavior
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Presence Editorial Board
U.S. Air Force Scientific Advisory Board

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HOUSE ARMED SERVICES COMMITTEE
EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE

STATEMENT OF

MR. FRANK KELLEY
DEPUTY ASSISTANT SECRETARY OF THE NAVY FOR UNMANNED SYSTEMS

BEFORE THE

EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE

OF THE

HOUSE ARMED SERVICES COMMITTEE

ON

ADVANCING THE SCIENCE AND ACCEPTANCE OF
AUTONOMY FOR FUTURE DEFENSE SYSTEMS

NOVEMBER 19, 2015

NOT FOR PUBLICATION UNTIL RELEASED BY THE
HOUSE ARMED SERVICES COMMITTEE
EMERGING THREATS AND CAPABILITIES SUBCOMMITTEE

Introduction

Chairman Wilson, Ranking Member Langevin, and distinguished members of the subcommittee, thank you for the opportunity to speak with you today. It is my pleasure to testify this morning beside Dr. Bornstein representing the Army, and Dr. Zacharias from the Air Force, as the Navy's first Deputy Assistant Secretary of the Navy for Unmanned Systems.

Chairman, I'm confident you will agree with me, by the conclusion of this hearing, that the research and development work the Navy and Marine Corps is conducting to improve autonomous capabilities in our future military systems is impressive, from the early research in cooperative behavior to autonomous takeoffs and landings of our unmanned aircraft. These innovations in autonomy, however, need to be nurtured and introduced in a manner which will gain the trust of our Sailors and Marines, and the public we are here to protect. In its significance, this is perhaps as much a military cultural evolution as it is a disruptive innovation. I hope the committee will come to appreciate the deliberate and disciplined nature in which the Navy and Marine Corps is investing time and resources in development and experimentation with this technology.

We are in the initial stages of creating a fully integrated manned and unmanned fleet. Unmanned technology will not replace our Sailors and Marines; instead it will unlock their full potential as we integrate unmanned technology with our total forces. Our focus is the establishment of an adaptable foundation that supports advances in related technology. It must also serve as a basis to develop interoperable, scalable and flexible capabilities for our military and allies to build upon as new threats emerge. This is imperative in order to stay ahead of our adversaries.

The Naval Research and Development Establishment (NR&DE), which includes the Naval Laboratories, Warfare Centers, Systems Centers, and the Office of Naval Research, has a long history of pursuing and embracing autonomous technologies to advance Naval warfighting capability. Leading scientists and engineers from across the NR&DE are working to understand how autonomous technologies should be developed and applied to realize a fully integrated manned and unmanned Fleet. In doing this, theDepartment of the Navy (DON) recognizes that we need to reach beyond our service and the Department of Defense (DoD), in partnership with

industry, academia and other government organizations such as the Department of Homeland Security's Federal Emergency Management Agency and U.S. Customs and Border Protection, USAID, and relief organizations such as the Red Cross to understand common applications and minimize unnecessary duplication of capability. Let us not forget, the Navy's mission encompasses everything from combat to peacekeeping to humanitarian assistance. I believe by partnering with these agencies that the Navy will not only retain the distinction of the world's premier naval power, but will continue to be America's guardian of peace, enabling the safe travel of people and goods to meet the expanding demands of globalization and free peoples.

Among the uniformed services of the United States, the Navy is distinct in the multi-dimensional conduct of missions on all fronts: in the air, on land, and on and under the sea. Given this unique mission set, the DON must maintain a diverse portfolio to deliver this capability in all domains, and we see autonomy as a technology to provide our systems greater utility so that man and machine can contribute. Since the notable successes of unmanned air systems in Desert Storm, the DON has continued to invest in this area, and has refined these investments to mature the technology we are discussing today - autonomy.

Many of you are familiar with the success that the Air Force has had with Global Hawk. The Navy has also taken note of its phenomenal persistence and capabilities, which have helped shape our investments in the MQ-4C Triton to provide the Navy with game-changing persistent maritime and littoral Intelligence, Surveillance and Reconnaissance (ISR) data collection and dissemination capabilities. Triton will be a key component of the Navy's Maritime Patrol and Reconnaissance Force family of systems. In this case, when I say "family of systems" I am referring to the collaboration between the unmanned aircraft Triton, and the manned aircraft P-8A Poseidon. This marks a significant step in the teaming and collaboration of our unmanned and manned platforms to deliver a major part of the military's surveillance strategy. While teaming in this instance is controlled by man, it will provide the foundation to evolve our manned-unmanned concept of operations to introduce autonomy as the technology and trust continue to mature. In the area of collaboration, we are taking full advantage of autonomy for our tasking, collection, processing, exploitation and dissemination, or TCPED efforts, to allow us to rapidly deliver situational awareness to our forces. While we are using autonomy to support

our “big data” needs, we are continuing efforts to harden our networks and advance our cyber security capabilities.

Autonomy

Autonomy is a rich and dynamic area of research today both within the military and more widely across government, industry and academia. While autonomy holds the potential to transform the way we conduct military and humanitarian operations in the future, it is important to understand that the word 'autonomy' can often be misrepresented and misunderstood. For example, some define autonomous systems as any system that senses and reacts to its environment. Alternatively, autonomous systems can also be defined as those having intelligence-based capabilities that allow them to respond to situations that were not pre-programmed or anticipated. We have acknowledged this debate, and recognize there is a broad spectrum of autonomous behaviors which define a system's ability to sense, comprehend, predict, communicate, plan, make decisions, and take sequential actions to achieve its objectives as determined through interaction with humans and between autonomous systems.

In our quest to better understand and define autonomy, the Office of Naval Research (ONR) is conducting basic research in robotic interaction/human factors; machine reasoning, learning and intelligence; perception-based control and decision-making including scene/image understanding; bio-robotics; decentralized control; cognitive science, and neuroscience. These fundamentals are the keys to designing and ultimately enabling the learning or teaching of collaboration and teaming capabilities among autonomous systems and between human and unmanned systems. We must understand the abilities and limitations associated with such technology in order to develop tactics, techniques and procedures that will improve our military’s operational efficiency and effectiveness.

The DON sees autonomy research as a key tenant in the process of building a consolidated long term vision for unmanned and autonomous systems, and the associated roadmap and investment strategy that supports our vision. As we think about this investment strategy, we recognize that there is a dynamic commercial industry in autonomy upon which we can leverage in areas where civilian and military applications overlap. Naval investments will

then be focused on autonomous challenges such as overcoming the challenges of operating in extreme, adversarial, and unknown environments, in maritime domains in which perception, communications, and mobility may be different from what is assumed in many commercial applications, and focusing on interoperability and other critical supporting architectures for the successful teaming of unmanned systems with our manned forces.

Acquisition and Experimentation

This past April, the Secretary of the Navy announced he was appointing a new Deputy Assistant Secretary of the Navy (DASN) for Unmanned Systems (UxS), who would help bring together all the many stakeholders and operators who are currently working on this technology in order to streamline their efforts. Additionally, OPNAV Director, for Unmanned Warfare Systems (N99) was established so that all aspects of unmanned, in all domains, will be coordinated and championed. As of November 2, 2015, both organizations have been officially stood up. Prior to that, the ground work commenced over the summer and the two organizations have collaborated with DASN Research Development Test & Evaluation (RDT&E) to develop a cross-Department prototyping and experimentation approach that embraces innovation. This approach will be used to "pull" capability gaps from the fleet and will empower integrated teams of technical subject matter experts, and fleet operators to quickly evaluate emerging technologies, engineering innovations, and/or new warfighting concepts.

Working with DASN RDT&E, we will prioritize and identify which of these gaps will be filled through prototyping and experimentation in the near term, or make recommendations to for basic and applied research. These assessments will be done through collaboration among laboratories, academia, and industry to develop rapid prototypes for fleet experimentation and evaluation. Part of the assessments will include risk analyses of cost, schedule, and performance and human-machine trade spaces. This process supports the 2012 Defense Science Board's recommendations for a three-facet (cognitive echelon, mission timelines and human-machine system trade spaces) autonomous systems framework, and should be considered as the initial unmanned and autonomous framework the Navy and Marine Corps will utilize to inform both the requirements and acquisition communities. The DON prototyping and experimentation

approach will ultimately shape DON investments in order to unlock the potential of this new technology, and shape the way our warfighters evolve to a future concept of operation.

The Defense Science Board also recommended creating new developmental and operational test and evaluation techniques to address the unique challenges of autonomy that will build "trust" in autonomous systems. DASN UxS also recognizes new test and evaluation strategies need to be explored to include improving modeling and simulation with unmanned and autonomous systems in order to validate consistent behavior and "fail safe" protocols. Gaining trust in the predictability of autonomous systems presents new challenges, especially in an environment both fiscally constrained and rapidly emerging, but must be examined and adapted in order to rapidly field, train and equip our warfighters. Employment of such capability will afford our military both tactical and strategic advantages and awareness necessary prior to engagement with our adversaries.

A challenge we face with rapidly developing and testing future technologies comes from supporting our operators in theater with disruptive solutions that fall outside the input for the Planning, Programing, and Budget and Execution cycle. One of my roles will be to find ways to change the way we conduct "traditional" acquisitions when promising technologies prove to exploit our defensive edge. As you may be aware, in January 2009, we fielded Broad Area Maritime Surveillance-Demonstrator (BAMS-D) as a six month demonstration providing intelligence to the warfighter in NAVCENT. It now has flown over 17,000 flight hours in support of NAVCENT and CENTCOM.

This capability serves as the basis for the follow-on TRITON Program of Record, but has defied the traditional acquisition and fielding process. Perhaps we will explore similar options for fielding "interim" solutions in a deliberate fashion until follow-on enduring solutions can support current operations.

Collaboration and Teaming

In support of collaborating and teaming research, ONR is investing in swarming and more generally in decentralized control technologies that will give our commanders a competitive edge through the development of group behavior techniques and swarming

mathematical algorithms that are not easily disrupted by an adversary and may operate in both focused groups and over large, complex areas. The Control Architecture for Robotic Agent Command and Sensing (CARACaS) is an autonomy architecture extended to enable technology that enables multiple unmanned surface vehicles (USVs) to autonomously "swarm" adversaries' ships, or swarm to protect high-value naval assets. This technology gives our warfighters a clear and decisive advantage on the water, both in littoral and high seas environments, allowing us to potentially engage without use of lethal force, but rather simply overwhelm the adversary.

This autonomy technology was successfully demonstrated in the summer of 2014 on the James River. Five fully autonomous USVs with some tele-operation necessary for safety reasons (confined waterway) operated collaboratively to demonstrate the escort of high-value assets and then intercepted a potential threat by swarming the target. The possibilities for use of this technology include but aren't limited to: anti-piracy, anti-terrorism, disruption of adversary coastal operations, asymmetric operations and high value asset protection. In an Anti-Access/Area Denial (A2/AD) environment, it can deter hostile actions, damage aggressive adversaries and potentially destroy an opposing vessel. Imagine if this technology existed when the USS Cole was attacked, or when the US-flagged MV Maersk Alabama cargo ship was hijacked. Although other applications for this technology are still being contemplated, it is important for the committee to know this technology didn't happen overnight; it has been 10 years in the making.

We are continuing investments in this area and are looking toward unmanned aerial vehicles (UAVs) to explore collaboration and teaming in three dimensions by adding altitude as the third component. Most recently, under the sponsorship of the Consortium for Robotics and Unmanned Systems Education and Research program, the Advanced Robotic Systems Engineering Laboratory (ARSENL) at the Naval Post Graduate School (NPS) recently demonstrated the successful autonomous flight of 50 UAVs simultaneously. The 50 UAVs were launched and flown autonomously in two "sub-swarms" of 25 UAVs each. The swarms were monitored using ARSENL-developed swarm operator interfaces. The UAVs performed basic leader-follower cooperative behaviors, and exchanged information amongst themselves via wireless links. NPS is also exploring multi-domain swarming with elements under, on, and over the water.

Low-Cost UAV Swarming Technology (LOCUST) is another ONR project that is using the Coyote, a small expendable unmanned aircraft system (UAS) deployed from an A-size sonobuoy tube or Common Launch Tube that performs ISR missions, and will be the focus of this autonomy technology development and insertion. The Navy is also planning a ship-based demonstration with 30 Coyotes to form a tactical swarm within the next year.

Logistic UAVs

In support of operations in Afghanistan, the Marine Corps deployed two KMAX, unmanned helicopters which delivered 6,000 pounds of cargo per day, keeping trucks off the road and delivering necessary supplies while keeping our warfighters out of harm's way. Conducting logistics operations is critical to allowing our forces to remain mobile and sustainable. However, it's during these resupply operations we suffer fatalities due to Improvised Explosive Devices, and ambushes alike. Based on the success of the KMAX, the Navy is investing in the Autonomous Aerial Cargo/Utility System (AACUS). This technology focuses on autonomous obstacle avoidance for unprepared landing sites with precision landing capabilities, including contingency management until the point of landing. AACUS provides a goal-based supervisory control component such that any field personnel can request and negotiate a desired landing site. This system will communicate with ground personnel for seamless and safe loading and unloading. This technology is also designed to be platform agnostic based on open architecture framework that allows it to be integrated in either manned or unmanned rotary–wing aircraft which can be operated in austere weather or tightly manned constraints.

Undersea

Unlike the other Services which operate on and above the surface, the Navy's extensive operations in the undersea domain present another level of complexity for autonomy and persistence capabilities. In order to maintain naval dominance, the Navy must invest in undersea technologies. One of the greatest challenges of operating in the undersea domain is that the Global Positioning System (GPS) is not an effective navigation system throughout this domain.

To that end, the Navy is investing in the Large Displacement Unmanned Undersea Vehicle (LDUUV) Innovative Naval Prototype (INP). This vehicle is advancing the state of energy, autonomy and endurance technologies for long-endurance, multi-mission undersea vessels in the littorals. Autonomy development under this program includes investments to monitor and improve reliability, advanced algorithms for undersea sensing and avoidance, as well as advanced techniques to perform missions requiring precision navigation and timing in the absence of GPS. Technologies developed under the ONR LDUUV INP have informed, and will continue to inform the Navy LDUUV associated program of record (POR) and further advances will enable future missions envisioned for this new system. This capability, once deployed, will allow submarines to focus on high priority complex missions that require "man-in-the-loop" while the dull, dirty and/or dangerous missions are conducted by the LDUUVs.

Another area where the Navy is investing in technology is the Anti-Submarine Warfare Continuous Trail Unmanned Vessel program. ONR has teamed with the Defense Advanced Research Projects Agency to design, build and demonstrate a clean sheet unmanned X-ship. This technology will free manned search platforms from being tied down in an asset-intensive continuous trail. The autonomous technology to enable the platform's ability to sense, process and react or trail is challenging much of the early efforts that have focused on the platform's ability to execute the rules of the sea, otherwise known as COLREGS. COLREGS are the International Rules formalized for Preventing Collisions at Sea. The development of autonomous behaviors to interpret these rules, and to sense, perceive, and react, is well underway.

Supporting Architectures

Open architectures, networking, and cyber security will be critical for the successful integration of autonomous and unmanned systems with our manned forces.

Open System Architectures and Interoperability

As we continue to develop unmanned and autonomous systems we need to establish interoperability standards. Open Systems Architecture (OSA) is both a business and technical strategy for developing a new system or modernizing an existing one. In order to address future

changes to the system and to ensure those changes will be cost-effectively integrated, the Navy and Marine Corps have been evolving to utilize OSA and base design strategies on widely supported open standards.

Establishing an OSA acquisition framework for UAS ground control systems started with an Acquisition Decision Memorandum (ADM) by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) in 2009. That ADM directed that the design of future interoperable capabilities would adopt a "common DoD architecture."

As a result, in the air domain, the UAS Control Segment (UCS) architecture development effort was initiated to provide common control for unmanned systems. This architecture defines the rules and conventions for interoperable and interchangeable software components. It is based upon Service Oriented Architecture principles, and provides a common basis for acquiring, integrating, and extending the capabilities of the control systems for UASs, while removing proprietary restrictions to enable seamless and simplified integration and reuse of UAS applications.

This Government-owned model can be imported directly into the development environment of the software developer or system integrator. Compliance with this architecture affords the DoD an agnostic UAS Ground Control System that theoretically can operate any unmanned air platform variant, regardless of Service. The Government has developed and owns the UCS Repository market place for the ground control system. The repository is a web-enabled online application "App" store, where vendors may advertise their products for procurement by DoD Service PMO/PoR and their industry contractors who are looking for UCS solutions that are ready for integration and fielding. This repository is similar to the commercial personal Smartphone industry, where unique applications can be downloaded to suit individual user needs or productivity requirements. Government, industry, and academia are encouraged to list their developed UAS service or application on the website for procurement (industry and academia) or reuse. This architecture is essentially a business model that will provide flexibility for unmanned air system control segment subsystems and components, control costs for development, reduces integration time for new capabilities, allows reuse across Service and Joint UAS programs, where appropriate.

An example of how this architecture is employed can be found in the Navy's Air Common Control System (CCS). This system will be capable of operating all Navy UAS (Fire Scout, Triton, and UCLASS) by focusing on commonality, interoperability, modularity and competition. CCS's program is a software solution with instantiations for multiple hardware configurations, is UCS Architecture and Naval Interoperability Profile compliant, and is built on a Government-managed Open Commercial-Off-the-Shelf (COTS) Framework that is scalable and modular. The initial CCS vehicle management capability is planned for fielding on Triton in Fiscal Year 2019.

The Navy is also working on adapting domain agnostic architectures that will allow for interoperability in multiple domains. Operating in each domain presents unique physical challenges. Domain interoperability allows for the flow of information and the high-level integration of unmanned systems with our manned forces.

The DON and Army initiated an open technology framework for the real-time and flight safety aspects of UAS designs as well. The Future Airborne Capability Environment (FACE) has over 80 companies (and growing) participating in a consensus-based consortium, managed by the standards body, The Open Group. The FACE approach is a Government-industry software standard and business strategy for development and acquisition of affordable and reusable software systems that promotes innovation and rapid integration of portable capabilities across global defense programs. The FACE standard is now required in 12 Navy and 13 Army contracts. The Hardware Open Systems Technologies (HOST) is a companion technical hardware standard for developing a physical plug-and-play environment for avionics computer components that will be used to support FACE conformant software.

Together, the FACE and HOST standards are establishing an OSA path for the development of open UAV systems in the aircraft, while the UCS standard establishes an OSA path for the control of the aircraft and interoperability of the data that comes from them.

Cyber Security

Fundamentally, the heart of autonomous systems is the intelligent, learning and adaptive software embedded within them. As such, cyber threats are a natural concern to autonomous

systems. Just as the Navy is aggressively pursuing research in autonomy and autonomous systems, the Navy is also pursuing research in cyber strategies in parallel. The Navy is investigating both vulnerabilities and possibilities for cyber that are unique to autonomous systems.

ONR research is developing foundational cybersecurity technologies to enable cyber-attack-resilient warfighting platforms, both manned and unmanned. With a specific focus on automated and semi-automated solutions, the goal of the ONR cyber science and technology program is to make it possible for warfighting platforms to "fight through" current and future cyber-attacks while assuring Command & Control of our platforms at the tactical edge.

By studying what makes cyber exploits successful in the first place, we have focused our research efforts on protecting against entire classes of attacks at once. This strategy has been employed across the ONR cyber science and technology program, from resiliency to complex software, and better positions the DoD to effectively monitor, detect, assess, mitigate, and recover against today's and tomorrow's cyber threats.

Networking - Beyond Line of Sight – Anti-Access/Area Denial (A2/AD) Environment

With the need to plan for operations in a GPS-denied environment, we have initiated research in Beyond Line of Sight capabilities. The NPS Distributed Information Systems Experimentation research group recently completed an ambitious series of experiments at Naval Air Weapons Station China Lake designed to create a mobile internet architecture that facilitates defense command and control requirements as well as ISR dissemination. The project, called Beyond Line of Sight Command and Control (BLOS C2), seeks to create a self-forming, self-healing network with Type I encryption and anti-jamming capabilities that can survive in satellite-denied environments.

Conclusion

General Gray, the 29th Commandant of the Marine Corps said, “Like war itself, our approach to warfighting must evolve. If we cease to refine, expand, and improve our profession, we risk being out dated, stagnant, and defeated.”

Integration of unmanned and autonomous based technologies are going to be "game changers" for Naval Concept of Operations. These technologies will become force multipliers in all domains providing capability on both tactical and strategic levels. In order to achieve this capability, the Navy will continue to conduct research, develop prototypes and experiments, and field as appropriate in all relevant areas. We will develop tactics, techniques and procedures for countering adversary use of unmanned and autonomous capabilities and specifically, include adversary use of autonomous systems in war games, simulations and exercises not constrained by U.S. Rules of Engagement.

It is our charge to push and maintain naval superiority by providing every advantage to our Sailors and Marines. This research will take time, resources, collaboration and risks. However, the Navy is committed. Planning and integrating these capabilities into our Fleet needs to be deliberate and robust in order to defeat our adversaries who do not play by our rules.

As Voltaire said, "With great power comes great responsibility" and pursuit of this technology must be disciplined with clearly articulated policies that will govern operation, and implementation. Our objective is to build capability that is not happenstance or reckless, rather sapient and judicious. The mission of the DON is to maintain, train and equip combat-ready Naval forces capable of winning wars, deterring aggression and maintaining freedom of the seas, and autonomous systems will play an important part. To that end, we will maintain the trust of the people we are here to protect, and quell any speculation of a dystopian world in the making.

With the rise in instability of Middle East, a fundamental deterioration in U.S.-Russian relations and A2AD challenges in the pacific, the Navy is confronted with challenges around the world. Given any unintentional military incident or political miscalculation could inadvertently put the United States into hostilities on multiple fronts, the use of unmanned and autonomous technologies need to be considered when we are discussing future strategies. The use of these technologies will help maintain advantage over potential adversaries over long periods of time and retain peace where possible.

Mr. Frank L. Kelley, Jr.
Deputy Assistant Secretary of the Navy (Unmanned Systems)
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Mr. Frank L. Kelley, Jr. currently serves as Deputy Assistant Secretary of the Navy (Unmanned Systems) (DASN (UxS)). He serves as principal advisor to the Assistant Secretary of the Navy (Research, Development and Acquisition) (ASN(RDA)) on all matters relating to unmanned systems across all domains (land, air and sea).

Mr. Kelley was selected to the Senior Executive Service in October 2015 following a 32 year career as a Unites States Marine.

Mr. Kelley, a native of Philadelphia, Pa., graduated from the University of Notre Dame in 1983 with a degree in Aerospace Engineering and was the recipient of the Naval ROTC Donald R. Bertling Award. Upon completion of Officer Candidate School (OCS), he was commissioned a Second Lieutenant in the United States Marine Corps.

In February 1984 he completed The Basic School and received orders to Pensacola, Fla., for flight training. He then proceeded to the 453rd Flight Training Squadron (FTS) at Mather Air Force Base, Calif., for electronic warfare training where he was a distinguished graduate and the recipient of the Colonel Mike Gilroy Award for leadership and training excellence.

After completing EA-6B Prowler training at Whidbey Island, Wash., he reported to Marine Tactical Electronic Warfare Squadron 2 (VMAQ-2), where he participated in the Unit Deployment Program, in addition to Operations Desert Shield and Desert Storm as the Contingency Plans and Tactics Officer.

His next assignment was at the Air Test and Evaluation Squadron (AIRTEVRON) FIVE (VX-5), where he was the Electronic Warfare Branch Head. He then reported to Naval Air Systems Command as the Avionics Systems Project Officer for the EA-6B.

He returned to the fleet as the Operations Officer for VMAQ-1 and then as the Assistant Operations Officer for Marine Aircraft Group 49 (MAG-49). He reported to the Pentagon as an action officer to the Deputy Assistant Secretary of the Navy (DASN) for Expeditionary Forces Program.

He attended the Marine Corps War College and taught at the Command and Staff College. He transferred to Marine Corps Systems Command (MCSC), Quantico, Va., where he was the Program Manager for Unmanned Systems. His next assignment was Military Assistant to Dr. Delores Etter, the Assistant Secretary of the Navy (ASN) for Research, Development and Acquisition (RDA).

In August 2007, he was assigned to the position of MCSC's Program Manager for Training Systems (PM TRASYS) in Orlando, Fla. In August 2009, he was reassigned as MCSC's Chief of Staff before being promoted to the rank of Brigadier General and assuming command of MCSC from July 2010 to July 2014.

He then served in the position of the Vice Commander, Naval Air Systems Command, preceding his last military assignment as Director for Prototyping, Experimentation and Transition in the office of the DASN for Research, Development, Test and Evaluation.

RECORD VERSION

STATEMENT BY

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BEFORE THE

HOUSE ARMED SERVICES COMMITTEE
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

FIRST SESSION, 114TH CONGRESS

ADVANCING THE SCIENCE AND ACCEPTANCE OF AUTONOMY FOR FUTURE DEFENSE SYSTEMS

NOVEMBER 19, 2015

NOT FOR PUBLICATION UNTIL RELEASED BY THE COMMITTEE ON ARMED SERVICES

Chairman Wilson, Ranking Member Langevin, and other distinguished members of the subcommittee, thank you for the opportunity to speak with you about the research and development work being pursued by the Army to improve the autonomy capabilities of future military systems, including the capability for collaboration and teaming between both autonomous and manned systems.

The Army Operating Concept – 2020-2040, recently published by the U.S. Army Training and Doctrine Command (TRADOC) Army Capabilities Integration Center (ARCIC), notes that

> "The application of emerging technology creates the potential for affordable, interoperable, autonomous, and semi-autonomous systems that improve the effectiveness of Soldiers and units. Autonomy-enabled systems will deploy as force multipliers at all echelons from the squad to the brigade combat teams. Future robotic technologies and unmanned ground systems (UGS) will augment Soldiers and increase unit capabilities, situational awareness, mobility, and speed of action. Artificial intelligence will enable the deployment of autonomous and semi-autonomous systems with the ability to learn. Decision aids will reduce the cognitive burden and help leaders make rapid decisions. Artificial intelligence may allow robots and automated systems to act with increased autonomy. Robotics will enable the future force by making forces more effective across wider areas, contributing to force protection, and providing increased capabilities to maintain overmatch.[1]"

The document provides the vision that "autonomous and semi-autonomous operational capabilities may increase lethality, improve protection and extend Soldiers' and units' reach." It also advises that "because technologies change rapidly and transfer easily, the U.S. military will have to accelerate new technologies into the force to maintain its ability to overmatch enemies." ARCIC, together with the Army's Science & Technology (S&T), Acquisition, Test and Evaluation, and Training and Doctrine communities, is developing the Robotics and Autonomous Systems strategy to

[1] Army Operating Concept, TRADOC PAM 525-3-1, October 2014

implement this vision, creating a roadmap for autonomy technology development, materiel acquisition, and training for the next 30 years. The materiel strategies and principles developed across the Army S&T enterprise[2] will contribute to this strategy.

In his recent presentation at the Reagan Presidential Library, the Deputy Secretary of Defense noted that a study by the Defense Science Board stated that autonomy technology has reached an "inflection point." The technology now is being pursued widely. It is being pursued globally and by the commercial sector. Almost daily we hear about its application by Amazon, Tesla, Uber and others. We see elements of the technology in many of the cars we drive. There are differences, however, between the commercial and the military application of the technology. Commercial usage generally focuses on benign, permissive, and structured environments. The military must design for adversarial, highly dynamic, and unstructured environments. The requirement for reliability and predictability of response in commercial applications reduces the requirement for learning, while unknown and dynamic conditions of tactical environments requires the system to learn and alter its behavior based upon experience.

The Army community has undertaken efforts for mid-term and more advanced far-term capabilities, in support of the Army's strategy, while also providing support for nearer-term efforts that will permit the Army to gain experience in complex software systems. TRADOC Centers of Excellence have used the ongoing Network Integration Evaluation (NIE) and beginning this fiscal year the Robotics Enhancement Program (REP) to place surrogate experimental autonomous systems in the hands of soldiers. Such experimentation will inform and aid development of future requirements, doctrine, tactics, techniques and procedures required to effectively employ this new capability, and is critical to gaining trust in this technology.

The Army recently concluded the Autonomous Mobility Applique System (AMAS) Joint Capability Technology Demonstration (JCTD) to provide possible initial solutions

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[2]Comprised of the Army Materiel Command (AMC) Research, Development and Engineering Command (RDECOM), the U.S. Army Corps of Engineers (USACE) Engineering Research Development Center (ERDC), the Space and Missile Defense Command/Army Forces Strategic Command (SMDC/ARSTRAT) Technical Center, the Medical Command (MEDCOM) Medical Research and Materiel Command (MRMC), and the Army G1, Army Research Institute for Behavioral and Social Sciences (ARI)

that the Army could use to adopt emerging autonomy technology aboard current platforms. The demonstration showed that tactical wheeled vehicles could navigate on roads at operational speeds as optionally manned vehicles, enabling the crew to spend time to improve situational awareness and survivability, while retaining the ability to assume vehicle control when required.

The technology architecture that was used in the demonstration separated the vehicle specific “drive-by-wire,” low level sensing and actuation from the true autonomous sensing and decision making for vehicle mobility. This paralleled the construct recommended by the 2012 Defense Science Board (DSB) Task Force on Autonomy in DOD Systems. The AMAS JCTD was a significant step for the introduction of autonomy technology for convoy operations. It provided a limited capability that is valuable both operationally and for providing feedback to shape future technology development. The Army will continue to build upon this initial capability to develop the technology that will expand the ability of vehicles to autonomously maneuver in all environments and appropriately react to unexpected events. Follow on efforts are underway in applied research and advanced technology development to increase the capabilities demonstrated in the JCTD and address technology gaps to move to a more autonomous convoy for resupply.

The S&T enterprise’s efforts are focused on seven main thrusts. It is focused on the maturation and demonstration of advanced manned/unmanned teaming for both air vehicles and ground vehicles that will permit unmanned assets to serve as “wingmen” to manned elements of the Force. The enterprise is also exploring effective teaming of unmanned air and ground vehicles. It is developing robotic technologies and capabilities that will enable unit resupply and sustainment operations using optionally-manned and unmanned vehicles and it is developing cognitive decision tools for effectively commanding teams of advanced Unmanned Air Systems (UAS). For the longer term it is conducting research focused on creating the technology that will seamlessly integrate unmanned elements, both ground and air, into small unit teams and research that will enable development of swarms of unmanned systems capable of effectively conducting military missions at range. Taken as a whole, these efforts will provide the underpinnings for autonomous systems that can operate side-by-side with

our Soldiers on the battlefield in applications ranging from unit resupply to reconnaissance and similar tactical operations.

Although the autonomy technologies available today work well for the sets of conditions for which they were designed and tested, they lack the flexibility and adaptability that would enable them to work well for other situations. Systems using today's technologies must be teamed with humans to supply the cognitive capability required for complex missions, while the unmanned element performs repetitive or persistent tasks. For example, even seemingly simple tasks such as exiting from a vehicle proved difficult for the robot competitors at the recent DARPA Robotics Challenge. Significantly advancing autonomy technology - taking machines from tool to teammate -will require technology advancement beyond what we have today. It will require that the soldier and the machine have common, though not necessarily identical, models of the world. It will require machines to reason more successfully, and to have an ability to learn from limited amounts of data. And it will require machines to infer desired actions based upon contextual knowledge or commander's intent. Humans excel at these cognitive skills, but machines currently do not. Army Basic Research efforts are directed towards these challenges, and we are making progress. For example, in the realm of machine teaming, researchers taking part in the Army Research Laboratory's (ARL) MicroAutonomous Systems and Technology (MAST) Cooperative Technology Agreement (CTA) have recently demonstrated micro-air vehicles with the ability to swarm, as well as maintain local reference without reliance upon GPS.

Perhaps the most critical roadblock to adopting autonomous technologies is ensuring that operators trust a system will do what it is supposed to on the battlefield. They will only gain this trust if we can demonstrate that these systems perform as advertised in complex, highly dangerous situations. Testing these complex systems will require methodologies very different from those utilized today. The introduction of learning, permitting software to modify its behavior with experience, will greatly complicate the testing process. The Army together with the other services is examining alternative paradigms for test and evaluation, exploring the use of licensure vice certification and continual evaluation, much as governments license drivers today.

We are also cognizant that autonomous systems, being complex computer systems on networks and potentially separated from the manned force, will be subject to cyber threats. To combat potential threats, the Army has been developing techniques for predicting how networks of systems reorganize to enable early detection of anomalous behavior. We are conducting research directed at learning for detection of cyber compromises and research on autonomous self-patching of cyber vulnerabilities as they are uncovered, among other areas. The goal is early detection and mitigation of cyber threats.

In conclusion, once again I would like to thank Chairman Wilson, Ranking Member Langevin, and other distinguished members of the committee for the opportunity to discuss the Army's role pursuing autonomy capabilities for future military systems. The Army is committed to developing autonomous systems that can work side by side with our Soldiers. I look forward to your questions.

Dr. Jonathan A. Bornstein

Dr. Bornstein has been intimately involved in robotics almost two decades. He has served as Chief of the Autonomous Systems Division, Vehicle Technology Directorate, Army Research Laboratory, since January 2010. He has responsibility for a group of approximately 30 Government and contractor personnel conducting research in perception, intelligence, and mechanics for unmanned vehicle systems and a micro-mechanics group focused on micro-autonomous systems. He manages the ARL Robotics Collaborative Technology Alliance and has responsibility for coordination of autonomous systems research throughout ARL. He previously served as Chief of the Army Research Laboratory Robotics Program Office (RPO) and as an engineer in the RPO. From 1995 through 1996 he served as a Program Manager at the Defense Advanced Research Projects Agency (DARPA) with responsibility for the Demo II Unmanned Ground Vehicle Program. Dr. Bornstein received his PhD. in Aeronautics & Astronautics from the Polytechnic Institute of New York. He received a U.S. Army Research & Development Achievement Award in 1989 and Army Superior Civilian Service Award in 1997.

QUESTIONS SUBMITTED BY MEMBERS POST HEARING

NOVEMBER 19, 2015

QUESTIONS SUBMITTED BY MR. WILSON

Mr. WILSON. In your testimony, you discuss the 4-year study you are doing to understand pilot trust in the Auto Ground Collision Avoidance Systems. How will the lessons of this study be applied to other platforms or domains?

Dr. ZACHARIAS. The AFRL Auto Ground Collision Avoidance Systems (AGCAS) acceptance study seeks to gauge pilot trust of the AGCAS system and to identify and validate the antecedents of trust for this highly-automated Air Force system. The lessons learned from this study will benefit the existing AGCAS system in the F–16 and will feed into the F–35 AGCAS implementation.

The study also investigates pilot attitudes toward a broad range of future automated technologies such as the Automatic Air Collision Avoidance System (AACAS), automated missile avoidance technologies, automated station keeping and refueling capabilities, and future concepts for autonomy such as autonomous Wingmen. These results garner insight into the factors that make a pilot more or less trusting of future automated technologies. Such information will be instrumental in avoiding pilot distrust of near-term capabilities such as the Integrated Collision Avoidance System, which integrates AGCAS and AACAS, as well as long-term capabilities such as autonomous Wingmen.

While the focus of the study is heavily focused on the air domain, I can easily see the lessons learned being folded into building space operator trust towards more automated station keeping algorithms and mission allocation. While this domain does not have the same risk to operator life that the air domain has, the long-term and financial consequences of mistakes are high. We will also examine the lessons learned for applicability to the cyber domain.

Mr. WILSON. In your testimony, you discuss the Low Cost Attritable Strike Unmanned Aerial System. What is the timeline for this program? What are some of the policy challenges that you think you will encounter as you demonstrate the technology?

Dr. ZACHARIAS. The currently open Broad Agency Announcement (BAA) for the Low Cost Attritable Strike Unmanned Aerial System seeks to provide a benchmark vehicle concept that we will build upon and use for future demonstration activities in an experimentation campaign plan. Contract award is targeted at January 2016 with the program challenging its participants to achieve first flight 24 months after contract award.

There are a number of policy challenges that will likely be encountered as we demonstrate this technology. The acquisition and ownership model of an attritable aircraft is a significant departure from traditional processes and policies, and is akin to treating the aircraft as a consumable or commodity product that can be procured with a short development cycle and significantly less emphasis on support and maintenance requirements.

With a short development and ownership timeline, life cycle operators will be able to acquire assets tailored for requirements as they evolve instead of lengthy modification of existing systems, which will enable quick tech refresh—common to the automotive industry. At the same time, these platforms will require an agile acquisition system, novel training systems that are more reliant on simulation, new roles and responsibilities for operators and maintainers, storage, and disposal. In addition, highly tailored air worthiness and certification considerations will pose challenges to the current acceptance practices and could change how and where we approach the use of unmanned systems.

Mr. WILSON. In dealing with test, evaluation, validation and verification, how are you working with the Test Resource Management Center to better understand where investments are needed for testing infrastructure, as well as where changes to the test "process" might be needed?

Dr. ZACHARIAS. The Air Force is working with the Test Resource Management Center (TRMC) primarily through the Test, Evaluation, Verification, and Validation (TEVV) Working Group of the DOD Autonomy Community of Interest (COI), of which both are active participants.

The Air Force is also supporting the TRMC Unmanned Autonomous Systems Test (UAST) Group—through the Autonomy COI TEVV working group—on a study de-

signed specifically to answer the question "How do we change our T&E infrastructure to accommodate future autonomous systems". This study, led by Georgia Institute of Technology, was a 20 month effort whose final report is scheduled to be delivered to TRMC by Jan 2016.

Finally, an example of collaboration between the Air Force, TRMC, and many others in identifying changes to the test process is a joint TRMC, AF Institute of Technology, and AFTC sponsored study on "How to conduct test and evaluation of autonomous systems and what specific testing methodologies and capabilities need to be addressed?" The study is led by the Scientific Test and Analysis Techniques Test and Evaluation Center of Excellence at AFIT in direct response to an inquiry by Dr. Brown (ASD/DT&E).

Mr. WILSON. What opportunities exist to conduct testing or experimentation with our international partners, including international non-governmental organizations?

Dr. ZACHARIAS. The U.S. engages in a wide range of T&E activities with partner nations. These opportunities include Reciprocal Use of Test Facilities, test range usage, weapons testing, and research. Collaborative work is codified in various forms. Government-to-Government agreements include provisions for information sharing legal liabilities, and shared funding. Cooperative Research and Development Agreements (CRADAs) are written agreements between private companies and government agencies to work together on projects. The Research Grants and Contracts program directly funds University and Foreign Laboratory basic research overseas through the Air Force Office of Scientific Research (AFOSR).

The Air Force continues to explore with those international partners, via collaborative technical exchanges, opportunities to advance autonomous research. The Air Force Research Laboratory has International agreements that facilitate collaborative autonomy research with our key partners. One example of effective collaboration is a multi-lateral under The Technical Cooperation Program (US/UK/CA/AU/NZ) agreement which is facilitating a Grand Challenge in autonomy research. AFRL is participating heavily in this effort focused on how best to approach Testing, Evaluation, Verification, and Validation internationally.

Mr. WILSON. The Navy and Marine Corps both have long histories of fleet experimentation, independently and as a naval team, as a way to test new technologies, new concepts and new ways of doing business. What resources do you expect to have to conduct experimentation? How will you integrate these activities into broader fleet exercises?

Mr. KELLEY. To accelerate the development and Fleet introduction of unmanned systems, the Department of the Navy recently established the Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN (UxS)), the Director, Unmanned Warfare Systems Division (OPNAV N99), and the Naval Rapid Prototyping, Experimentation, and Demonstration Office, within Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation (DASN(RDT&E)). Working together, these new organizations will accelerate the practice of experimenting with developmental and operational prototypes to address Navy and Marine Corps operational needs. DASN (RDT&E) will leverage the Naval Research and Development Establishment's (NR&DE) vast technical capabilities, laboratories, major ranges, and test facilities to develop, integrate and experiment with advanced naval prototypes. DASN (RDT&E) provides the avenue to focus and integrate resources from across the DON and the DOD programs working closely with Fleet Forces, Warfighting Development Centers, and the Marine Corps Combat Development Command. Prototypes will be incorporated into Fleet experiments, such as: RIMPAC, Trident Warrior, Bold Alligator, Unmanned Warrior, etc., enabling technical and operational assessments of emerging operational concepts, technologies, and/or engineering innovations.

Mr. WILSON. The subcommittee is familiar with the DARPA investments in Anti-Submarine Warfare Continuous Trail Unmanned Vessel, or ACTUV, program. What plans does the Navy have to experiment with that platform?

Mr. KELLEY. The Office of Naval Research will integrate ONR-developed payloads and autonomous control components and perform at-sea testing of the DARPA ACTUV vessel, in its "Medium Displacement Unmanned Surface Vessel (MDUSV)" program. The payloads are for mine countermeasures, anti-submarine warfare and electronic warfare missions. The at-sea testing will be focused on these payloads, the mission capability they provide, as well as extensive testing of ACTUV's autonomous control system.

Mr. WILSON. In dealing with test, evaluation, validation and verification, how are you working with the Test Resource Management Center to better understand where investments are needed for testing infrastructure, as well as where changes to the test "process" might be needed?

Mr. KELLEY. DASN UxS will leverage the existing construct within DON that is responsible for ensuring the test community is ready to support required testing. This construct, led by DON T&E, is responsible for collaborating across the ranges/labs/warfare centers, programs/PEOs and the rest of the test community to determine requirements for future autonomous systems, gaps in current T&E Infrastructure, and identification of future investments and/or changes to the test process.

a. DON T&E will continue to be the primary interface with TRMC who is sponsoring an Autonomy T&E Study with an objective of assessing the adequacy of the test resources and infrastructure required to test autonomous systems. The study, which is being conducted by Georgia Tech, will also develop a time-phased investment strategy to address potential shortfalls in T&E capabilities.

b. The study team is coordinating closely with the Autonomy Community of Interest (COI), Test & Evaluation and Verification & Validation (ATEVV) Working Group.

c. The Navy is actively engaged in the study with participation from OPNAV, ONR, NRL, NAVAIR and NAVSEA.

i. Several Naval programs are being considered in the study such as the Autonomous Aerial Cargo Utility System (AACUS), Unmanned Carrier-Launched Airborne Surveillance and Strike system (UCLASS), and Large Displacement Unmanned Undersea Vehicle (LDUUV). In addition, DARPA's Anti-Submarine Warfare Continuous Trail Unmanned Vehicle (ACTUV) is also a key consideration.

ii. NAWC–AD, NAWC–WD, NSWC Keyport, and NSWC Newport T&E personnel are working with the study team to examine the future state of autonomous systems, and identify the required T&E/experimentation/assessment/certification infrastructure, technology, capabilities and workforce required to address future autonomous systems.

Mr. WILSON. What opportunities exist to conduct testing or experimentation with our international partners, including international non-governmental organizations?

Mr. KELLEY. Joint Warrior is a United Kingdom led bi-annual (spring and autumn) multi-national exercise which takes place in Scottish Exercise Areas. In October 2016 an additional exercise will be conducted in coordination with the Joint Warrior Exercise, referred to as Unmanned Warrior. The objective of this exercise is to experiment with the tactical employment of unmanned and autonomous systems in the maritime and littoral environments. Significant UK defense industry and NATO participation is anticipated, and this will be an opportunity for the Navy to conduct testing with our international partners.

Mr. WILSON. You mentioned in your testimony that the Army will be continuing work to increase the capabilities offered as part of the Autonomous Mobility Applique Systems (AMAS) Joint Concept Technology Demonstration and addressing some of the technology gaps in autonomous convoy resupply. What are some of those gaps as you see them?

Dr. BORNSTEIN. The AMAS JCTD, and subsequent demonstrations, focused upon an incremental approach for the creation of a "fail-safe architecture" that would permit the reduction of crew size from two Soldiers to a single individual. In effect, this program was utilizing technology to create driver's aids analogous to the safety features that are now beginning to appear in both private and commercial vehicles. While having direct benefits, especially under tactical situations, significant technology gaps exist that prevent immediate deployment of autonomous vehicles. These gaps include the development of an appropriate software architecture, algorithms for perception and vehicle behaviors, and the integration of those algorithms into the software architecture so that they can operate in real time, i.e., permitting vehicles to operate at appropriate tactical speeds. Some of the required technology will benefit from research and development activities currently being conducted in the private sector, e.g., Google and others. However, Google and others are depending on robust wireless networks to support their applications. Unfortunately, these networks may not be available in the dynamic and complex tactical environments the Army may be working which creates additional challenges.

Mr. WILSON. In dealing with test, evaluation, validation and verification, how are you working with the Test Resource Management Center to better understand where investments are needed for testing infrastructure, as well as where changes to the test "process" might be needed?

Dr. BORNSTEIN. The OSD Autonomy Community of Interest (COI) has recognized that the test and evaluation/validation and verification (T&E/V&V) of future intelligent systems that incorporate learning leading to emergent behaviors is critical to future employment of systems incorporating this technology. It therefore created the T&E/V&V working group. Since the COI is a "grass roots" organization that incorporates all individuals with common interests, it has worked hand-in-hand with the Test Resource Management Center (TRMC) Unmanned and Autonomous System

Test (UAST) program in furthering common goals. Members of the T&E/V&V working group are part of the UAST working group, while members of the UAST, including the executing agent, participate in the Autonomy COI T&E/V&V effort.

The functions that the T&E/V&V working group set for itself are to foster community collaboration; develop an S&T strategic roadmap, including an assessment of current autonomy T&E and V&V standards, procedures, infrastructure, and capabilities; identify gaps where those capabilities, infrastructure, and policy are misaligned or deficient; coordinate with Major Range Test and Facility Base (MRTFB) to produce a database baseline of T&E infrastructure; and support standards development unique to the V&V of autonomous systems.

The working group has established five goals: (1) creation of methods and tools assisting in T&E/V&V requirements development and analysis, (2) further adoption of evidence-based design and implementation, (3) employment of cumulative evidence through the research and development, test and evaluation, developmental testing, and operational testing phases of system life cycle, (4) adoption of methods for run-time behavior prediction and recovery, and (5) development of assurance arguments for autonomous systems. The working group has established a charter, published an investment strategy, and developed a strategic roadmap. The working group has presented its investment strategy to the UAST and each group has presented its projects to the other group. The Autonomy COI is directly supporting the ongoing TRMC sponsored T&E study administered by the Georgia Tech Research Institute. The study's objective is to evaluate the adoption of a pedigree-based licensure paradigm, vice certification, for future autonomous systems.

Mr. WILSON. What opportunities exist to conduct testing or experimentation with our international partners, including international non-governmental organizations?

Dr. BORNSTEIN. The Department of Defense (DOD), through the Services or jointly through the Office of the Secretary of Defense (OSD), maintains a robust set of relations with international partners under established cooperative research, development, testing and evaluation bilateral or multilateral agreements. On the topic of robotics, the Army maintains agreements with Australia, Canada, France, Germany, Israel, Japan, Korea, and the United Kingdom. In past years, the Army conducted a joint competition with the Australian Defense Science and Technology Office specifically focused on small autonomous ground robotic vehicles conducting intelligence, surveillance, and reconnaissance (ISR) missions in complex environments; the final competition was held in Adelaide, Australia. Over the course of the next few months, Army personnel are scheduled to visit their government counterparts in France and Israel to discuss specific collaborative research opportunities in robotics, autonomy and unmanned vehicles. The Army is also conducting exploratory discussions in the area of robotics with potential new partners, such as India and Singapore. Over the past 18 months, two projects have been under discussion between DOD and India's Center for Artificial Intelligence and Robotics (CAIR) focusing on "Improving Cognitive and Artificial Cognition Models" and "Small Intelligent Autonomous System for Situational Awareness."

DOD researchers are actively involved in The Technical Cooperation Program (TTCP), a joint research collaboration among the defense establishments of the US, UK, Canada, Australia, and New Zealand. The Autonomy Strategic Challenge Group within the TTCP envisions manned and unmanned assets working in concert, employing autonomy technologies to efficiently and cost-effectively support joint coalition force structures. To this end, the group is developing a set of challenge problems to collectively advance autonomy technology.

In addition, initiatives such as the Engineer and Scientist Exchange Program (ESEP) and Cooperative Research and Development Agreements (CRADA) offer DOD researchers the opportunity to conduct joint projects addressing technology gaps and interoperability solutions with foreign partners, either in government, academia or the commercial sector. Under the ESEP, U.S. Defense personnel are temporarily assigned to work in allied and friendly country defense establishments on topics of shared strategic interest. CRADAs are formal agreements between one or more Federal laboratories and one or more non-Federal parties under which the parties provide personnel, funds, facilities, equipment or other resources to conduct specific research or development efforts.

Lastly, The Army uses two OSD programs in order to collaborate with foreign partners—Coalition Warfare Program (CWP) and Foreign Comparative Test (FCT). CWP supplements Army funding for specific cooperative development projects with our allies and foreign partners. The projects accomplish mutual research, development, and interoperability goals through equitable contributions from all partnering nations. The FCT program typically involves U.S. purchase of foreign materials/products in order to test and evaluate novel technologies.

QUESTIONS SUBMITTED BY MR. LANGEVIN

Mr. LANGEVIN. All witnesses, how are you leveraging the Department's laboratory enterprise and academic relations for advances in autonomous capabilities, in addition to industry?

Dr. ZACHARIAS. The Air Force is leveraging the Department's laboratory enterprise and academic relations extensively for advances in autonomous capabilities. As mentioned in my written statement, the Air Force's primary agent for autonomy research, the Air Force Research Laboratory (AFRL), commissioned the development of the AFRL Science and Technology (S&T) Autonomy Vision and Strategy in 2013. This document identifies the major goals, technical challenges, and investment strategies needed to discover, develop, and demonstrate warfighter-relevant autonomy S&T to maintain and enhance air, space, and cyberspace dominance. This strategy has been coordinated with the other services and with OSD through the Assistant Secretary of Defense for Research and Engineering's (ASD(R&E)) Autonomy Community of Interest (COI). My written statement also went into detail on AFRL's autonomous systems research and development efforts, on-going or planned. Some examples of how the Air Force is leveraging the laboratory include:

- AFRL's Human Effectiveness Directorate has an ISR Analyst Test Bed which provides a research-representative Processing, Exploitation and Dissemination (PED) cell for developing interfaces and technologies. Outputs of this research, the Internet Relay Chat Coordinate Extractor (ICE) and Enhanced Reporting Narrative Event Streaming Tool (ERNEST), not only improve manpower efficiencies and reduce airman workload, but also lay the groundwork for integrated multi-INT autonomous processing and advance analyst cuing via autonomous decision-aiding.
- The current integration of an Auto Ground Collision Avoidance System (Auto GCAS) into the Air Force's operational F–16 fleet is an example of how the focus on human-machine teaming and the need to develop trust across the team can build acceptance of autonomous systems within the Air Force. The system was developed jointly by five organizations working closely together: AFRL; Lockheed Martin's Advanced Development Programs (ADP), also known as the Skunk Works®; the Office of the Undersecretary for Personnel and Readiness; NASA's Armstrong Flight Research Center; and the Air Force Test Center.
- AFRL is currently collecting proposals for a Low Cost Attritable Strike Unmanned Aerial System (UAS) Demonstration that will design, develop, assemble, and test a technical baseline for a high speed, long range, low cost, limited-life strike Unmanned Aerial System (UAS). The program will also identify key enabling technologies for future low cost attritable aircraft demonstrations, and provide a vehicle for future capability and technology demonstrations. AFRL's primary agent for interfacing with academia is the Air Force Office of Scientific Research (AFOSR) which has two primary portfolios supporting the advancement of autonomous capabilities: Computational Cognition and Machine Intelligence and Trust and Influence. The Computational Cognition and Machine Intelligence portfolio supports experimental studies and computational modeling to allow autonomous systems and mixed human-agent teams to achieve human-level performance with minimal interaction and provide warfighters with decision-making support in C4ISR environments. Examples of projects funded by this portfolio include "Neurocognitive Information Processing" with Columbia University, "Circuit Models for Robust, Adaptive Neural Control" with Tulsa University, and "Making and Keeping Informed Commitments in Human-Machine Systems" with the University of Michigan.

The Trust and Influence portfolio explores the sciences of reliance (how do humans establish, maintain, and repair trust, in others and in autonomous systems) and influence (how to shape the behavior, attitudes, or beliefs of others). Examples of projects funded by this portfolio include "Stochastic Logical Reasoning for Autonomous Mission Planning" with Rensselaer Polytechnic Institute (RPI) and "Findings on Universal, Cross-Cultural Linguistic Features Associated with Veracity and Deception" with San Francisco State University.

Additionally, AFOSR has several portfolios with grants that are directly applicable to autonomy. The Human Performance and Biosystems portfolio has several grants on autonomy-related topics to include a Center of Excellence named the Nature Inspired Sciences Flight Technologies and Ideas (NIFTI). A Center of Excellence is a 5-year program where an AFRL Technical Directorate partners with AFOSR to co-fund a university or group of universities to develop a particular area of science that the lab wants to eventually internalize. This particular Center is at the University of Washington, but also includes Maryland, Case Western Reserve, and Johns Hopkins Universities. There is also a Partnership Agreement with the United Kingdom entitled "Biologically Inspired Technologies for Unmanned Autonomous Systems."

The Computational Mathematics and Optimization portfolios have funded several tasks with the key-words of "autonomous decision", "automated routing", "autonomous navigation", "automatic task assignment", and "flocking". From 2010 on, AFOSR has made between $4M and $5M investment towards these topics. This includes a $500K/year "lab-task" (a 5-year award) to AFRL's Munitions Directorate which operates as a Center of Excellence with multiple tasks performed by the University of Florida and collaborators. The scope of work of the Mathematical Modeling and Optimization Institute (MMOI) is varied and was recently reviewed by the Air Force's Scientific Advisory Board with positive feedback.

Mr. LANGEVIN. All witnesses, have you received guidance or direction on advancing autonomous capabilities as part of the Third Offset Strategy?

Dr. ZACHARIAS. The Air Force has not as of yet received official guidance or direction on advancing autonomous capabilities as part of the Third Offset Strategy but is posturing itself to be responsive to any provided guidance and/or direction from the Office of the Secretary of Defense.

In a recent speech at the Reagan Defense Forum, Deputy Secretary of Defense Bob Work stated that the "big idea" behind the Third Offset Strategy was "human-machine collaboration and combat teaming."[1] He then said that this realization came from two major efforts: the Long Range Research and Development Planning Program (LRRDPP) and the 2015 Defense Science Board summer study on autonomy.

The AF was involved in LRRDPP over the last calendar year and is currently awaiting guidance on what portions of the program to implement. In his FY18 Air Force Science and Technology (S&T) Programming Guidance (dated 27 Oct 2015), the Assistant Secretary of the Air Force (Acquisition), Dr. William LaPlante, directed AFRL to place emphasis on the LRRDPP as detailed in the FY17–21 Defense Planning Guidance as it builds its FY18 budget input for its S&T Program.

Based on AFRL's extensive portfolio for advancing autonomous capabilities, as discussed in my written statement, I do not expect that supporting LRRDPP recommendations will require significant changes to existing programs.

Mr. LANGEVIN. All witnesses, to what extent are you exploring autonomy in cyber capabilities?

Dr. ZACHARIAS. AFRL is exploring autonomy primarily for defensive cyber capabilities. The two main efforts are the Autonomous Defensive Cyber Operations program and the Cyber Grand Challenge (in collaboration with DARPA), both of which are described below. Additionally, we are beginning to apply machine learning capabilities to the Command and Control (C2) cycle, allowing for multi-domain C2 to occur across air, space, and cyberspace operations by having systems make recommendations based off prior experience throughout the planning, targeting, weaponeering, tasking, and assessment process.

We are moving from "man in-the-loop" to "man on-the-loop" and allowing computers to carry out more of the workload, which provides the potential to increase current decision-loop speed and quality. Currently, effective cyber operations require that human operators make complex decisions from massive amounts of data in near real time. Incorrect decisions can arise from an operator missing a piece of information. Correct conclusions may be reached manually, but if they are not acted on in a certain timeframe (milliseconds or less), they may not deliver the intended effect. Simply put, outpacing the decision cycle of an adversary requires machine speeds. The Autonomous Defensive Cyber Operations (ADCO) program's goal is to research approaches and technologies to create force multipliers for cyber operations through the use of machine learning and artificial intelligence. The team is developing and demonstrating proofs of concept that integrate machine leaning and artificial intelligence into defensive cyber operations processes for the purposes of reducing the manual burden on Cyber Protection Teams (CPTs). These proofs of concept will be used to assess the effectiveness in these approaches, to understand the level of confidence in autonomous defensive systems, and to identify legal and policy challenges that must be overcome for the successful integration of autonomy into defensive cyber operations. The Cyber Grand Challenge (CGC) program requires teams to build fully automated systems that can find vulnerabilities in software, prove that they have found the vulnerability by synthesizing an input that will trigger the vulnerability, patch and nullify the vulnerability with acceptable performance overheads, and incorporate game theory to win a competition where these machines are competing against each other.

The CGC's Qualification Event took place in June of 2015 with the following highlights:

[1] "Reagan Defense Forum: The Third Offset Strategy," As Delivered by Deputy Secretary of Defense Bob Work, Reagan Presidential Library, Simi Valley, CA, November 7, 2015

1. Machines can find, prove, and fix almost all of the vulnerable programs in the test space.
2. Most vulnerabilities were patched within the first two hours of the 24-hour competition. The machines found unintended vulnerabilities that evaded even the software's authors without the need for source code or debug symbols.

AFRL was involved in all aspects of the Qualification Event, but specifically led the infrastructure design and post mortem analysis of submissions. The machine versus machine competition will take place in August of 2016.

Mr. LANGEVIN. All witnesses, how are you leveraging the Department's laboratory enterprise and academic relations for advances in autonomous capabilities, in addition to industry?

Mr. KELLEY. The Navy has a long history of advancing autonomous Naval warfighting capabilities across all domains: air, ground, sea, space, and cyber space. However, as the rate of change in the global environment accelerates and the landscape of potential threats shifts more rapidly than ever before, the DON recognizes that we must accelerate the adoption of technological advances, to include autonomous capabilities. To accelerate the development and Fleet introduction of unmanned systems, the Department of the Navy recently established the Deputy Assistant Secretary of the Navy for Unmanned Systems (DASN (UxS)) and the Director, Unmanned Warfare Systems Division (OPNAV N99). OPNAV N99, working closely with DASN (UxS), are the Navy's innovation leaders to get emerging unmanned systems and related capabilities to the Fleet quickly. Additionally, the Department of the Navy (DON) has recently established the Naval Rapid Prototyping, Experimentation, and Demonstration Office, within Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation (DASN (RDT&E)). In this role, DASN (RDT&E) has been given authority to leverage the Naval Science and Technology (S&T) community, the Naval Research and Development Establishment (NR&DE), and our talented Sailors and Marines.

The Navy also plans on leveraging its established business processes and contracting vehicles to reach out to industry and academia (including University-Affiliated Research Centers and Federally Funded Research Centers). These processes are in place through a variety of organizations such SYSCOMs, PEOs, and Warfare Centers among others.

OPNAV N99, in coordination with DASN (UxS), is developing an unmanned system autonomy strategy focused on a common, multi-domain autonomy architecture which will leverage many of the autonomy developments to date. The goal is to capitalize on these individual system developments to form a more complete, modular system that is capable of operating on not just a single system, but rather across systems and across domains. With the increasing numbers of expected unmanned systems coming in the future years, this is a sustainable method for autonomy development.

Mr. LANGEVIN. All witnesses, have you received guidance or direction on advancing autonomous capabilities as part of the Third Offset Strategy?

Mr. KELLEY. The Navy is aware of the key role of autonomous capabilities as part of the Third Offset Strategy. The Navy has been advancing autonomous capabilities for several years through science and technology investments and our unmanned system programs. The Navy will continue to identify how we can further advance these capabilities and rapidly introduce them to the Fleet in order to achieve the Third Offset Strategy.

Mr. LANGEVIN. All witnesses, to what extent are you exploring autonomy in cyber capabilities?

Mr. KELLEY. Adversarial cyber interaction occurs at a speed beyond what human can comprehend. The complexity and internal operating speed of cyber systems are many orders of magnitude beyond what human operator can timely observe, comprehend and response, resulting in the defender total reliance to forensic (after the fact) process, which may result in significant damage and expensive recovery.

Full autonomy in cyber space is a long term goal of the Navy's cyber security research at ONR for both the computing devices and the networking infrastructure. By full autonomy, we mean a system that closes the loop of sensing, analyzing, planning and taking action at cyber speed. Autonomic cyber systems employ machine-situational awareness and advanced machine reasoning to understand their operating status and environment, plan for actions, mitigate and inoculate against cyber exploits.

For near and mid-term, we are developing technologies for automating sensing, analysis and recommending plans for actions to human operator.

Mr. LANGEVIN. All witnesses, how are you leveraging the Department's laboratory enterprise and academic relations for advances in autonomous capabilities, in addition to industry?

Dr. BORNSTEIN. The U.S. Army Research Development and Engineering Command's (RDECOM) Army Research Lab's (ARL) Open Campus is a collaborative business model, with the goal of building a science and technology ecosystem that will support groundbreaking advances in basic and applied research areas of relevance to the Army. The global academic community, industry, small businesses, and other government laboratories benefit from this collaboration with ARL's specialized research staff and unique technical facilities. These collaborations will build research networks, explore complex and singular problems, enable self-forming expertise-driven team building that will be well-positioned for competitive research opportunities, and expose scientists, engineers, including professors and students, to realistic research applications and perspectives. Specific to autonomous capabilities research, ARL's campus features a 9,800 square foot Urban Experimental Facility for autonomous systems and sensing.

The tools available to aid the laboratory in its collaborative business model through Open Campus include Educational Partnership Agreements (EPAs) and Cooperative Research and Development Agreements (CRADAs).

EPAs are used to encourage and enhance education and research opportunities with academia in science, technology, engineering and mathematics disciplines relevant to ARL science and technology programs. Under EPAs, visiting students have access to world-class research facilities and are able to work side-by-side with subject-matter experts in their fields of interest. In turn, ARL is able to increase the awareness and visibility of technologies developed by the military and to encourage and enhance study in scientific disciplines at all levels of education.

CRADAs provide an easy way to collaborate with ARL. A CRADA is a formal agreement between one or more Federal laboratories and one or more non-Federal parties under which the Government, through its laboratories, provides personnel, facilities, equipment or other resources with or without reimbursement (but not funds to non-Federal parties). The non-Federal parties provide personnel, funds, services, facilities, equipment or other resources to conduct specific research or development efforts that are consistent with the mission of the laboratory.

Mr. LANGEVIN. All witnesses, have you received guidance or direction on advancing autonomous capabilities as part of the Third Offset Strategy?

Dr. BORNSTEIN. At this time, there has not been any specific guidance nor direction on advancing autonomous capabilities specifically as part of the Third Offset Strategy. However, the Army is leading the DOD's revolutionary approach to aviation development with Future Vertical Lift (FVL), an initiative to develop the next generation of vertical lift aircraft for the Joint Warfighter, with the goal of getting to low-rate production by 2030. The Army Science and Technology Joint Multi-Role Technology Demonstrator (JMR TD) effort will inform technology options and reduce risk for the FVL program of record. The JMR TD effort will demonstrate optionally piloted or autonomous flight capabilities. The Army is also involved in manned-unmanned teaming efforts such as flying AH–64 Apache helicopters together with Gray Eagle and Shadow UAVs as, effectively, remotely controlled extensions of the manned Apache's onboard sensors.

Mr. LANGEVIN. All witnesses, to what extent are you exploring autonomy in cyber capabilities?

Dr. BORNSTEIN. The Army is conducting R&D efforts on a number of topics that will help enhance autonomous capabilities of cyber technologies, such as autonomous agents operating on the network to detect, mitigate, and prevent cyber threats. These efforts include the following:

- Research on unsupervised learning for detection of cyber compromises, particularly relevant to autonomous systems that operate for a relatively prolonged time under cyber threats and possibly with limited opportunities for human intervention.
- Research on "light-weight" cyber intrusion detection agents, which can be deployed on platforms with constrained computational power.
- Research on autonomous self-patching of cyber vulnerabilities as they are uncovered, especially on mobile tactical devices.
- Research on agile (and largely autonomous) reconfiguration of networks and entities on the networks, to minimize exposure to cyber threats or contain an already inflicted cyber damage.
- Development of algorithms that can map cyber threat to mission impact to provide traceability between intruder actions and Brigade Combat Team (BCT) networks and autonomy enabled platforms.
- Development of correlation algorithms to fuse defensive cyber, spectrum awareness, offensive cyber, and network awareness information to enable BCT analysts to perform internal hunt activities in an incident friendly environment.

The Army is also assessing the impact of the cyber threat to future autonomous systems; developing cyber behavior monitoring models/techniques for tactical radio waveforms to enable anomalous behavior detection; developing trusted authentication techniques that do not rely on reach-back to centralized authorities; conducting research to track data flows, monitor data modification, and ensure trusted pedigree of information across the tactical network; and researching cyber containerization techniques to block and restrict the spread of malware on tactical mission platforms.

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